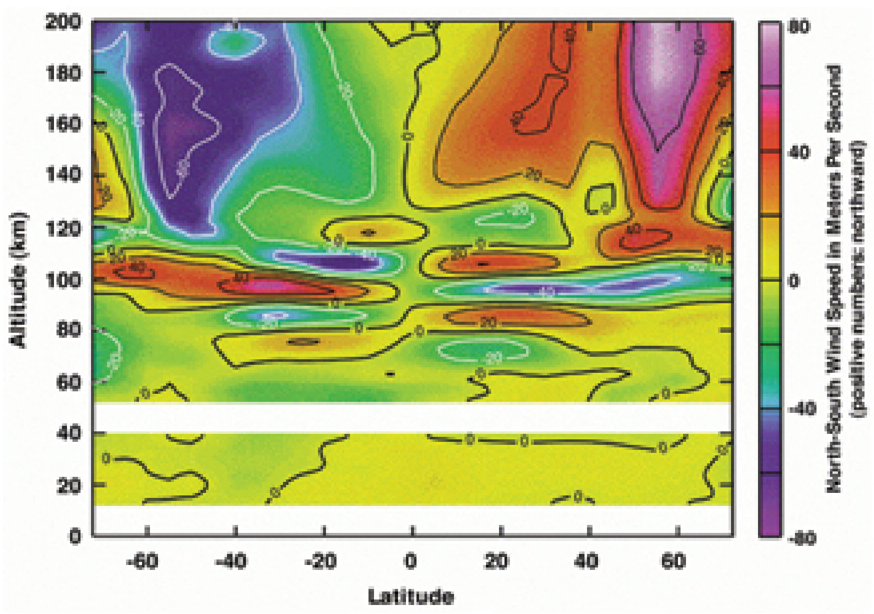
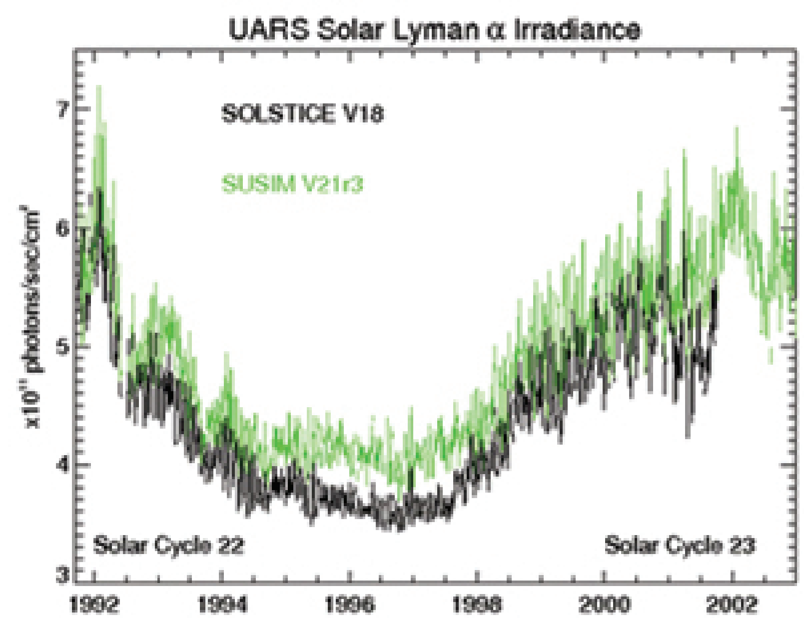
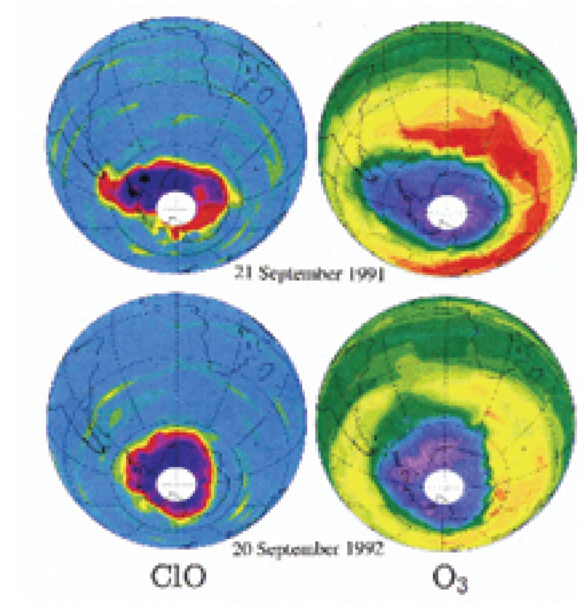
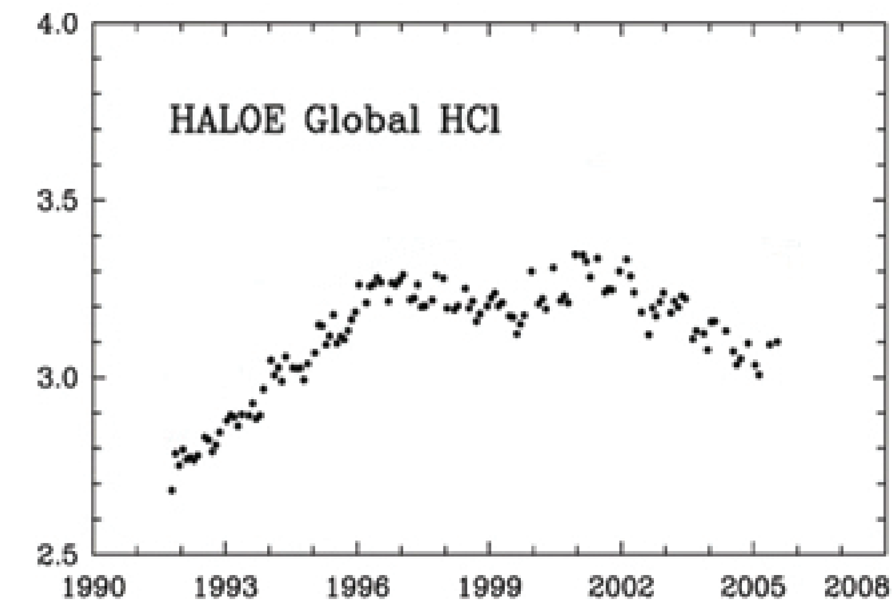
Laboratory for Atmospheres 2005 Technical Highlights

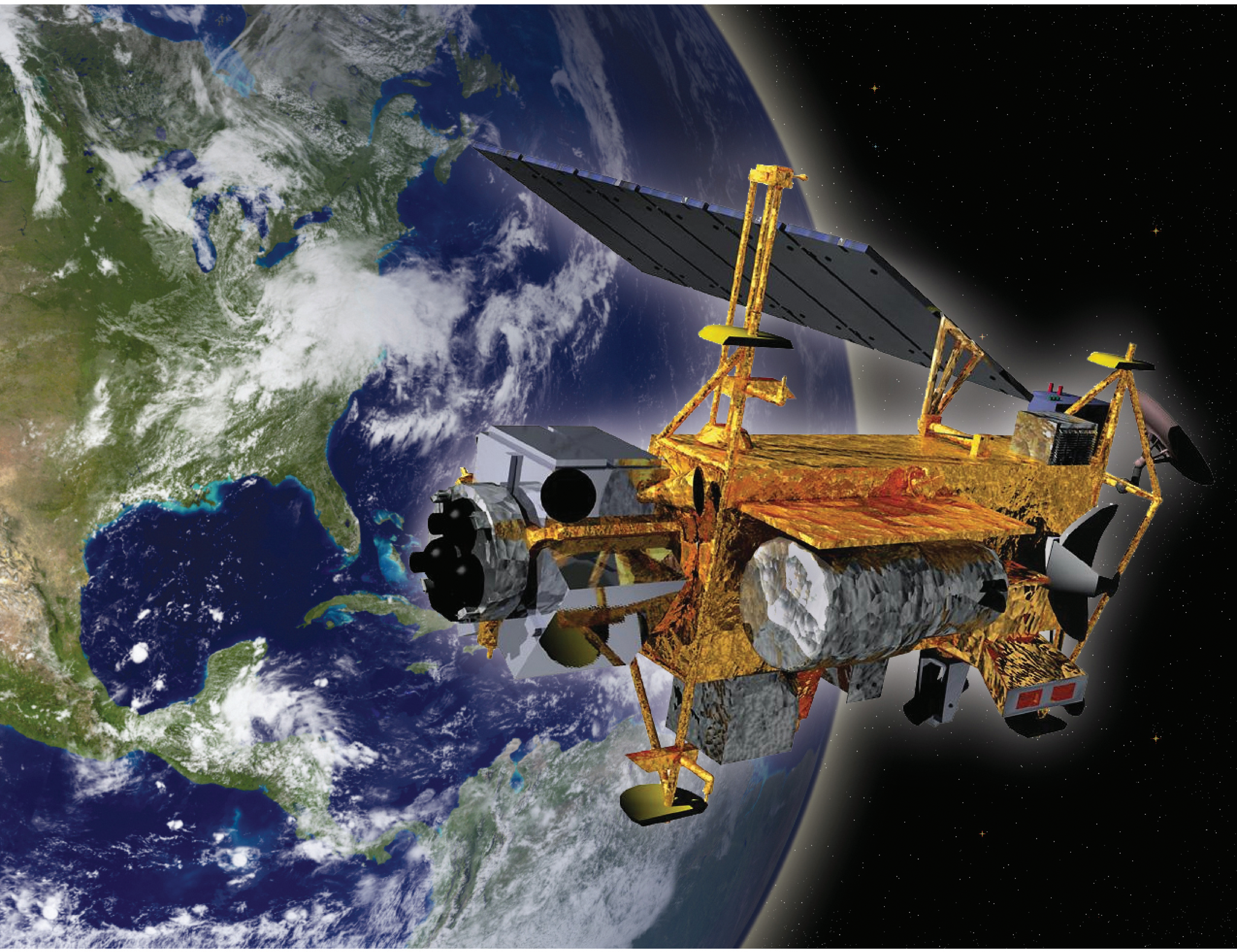
DRAFT











National Aeronautics and Space Administration

Goddard Space Flight Center, Greenbelt, Maryland 20771

March 2006

Cover Caption

Central figure. Artist's concept of the Upper Atmosphere Research Satellite (UARS) orbiting above Earth. UARS was launched in September 1991 and decommissioned in December 2005, after a 14-year mission.

Graphics at top of cover page (left to right):

Far left. Composite of measured meridional winds from the UARS High Resolution Doppler Image (HRDI) and Wind Imaging Interferometer (WINDII) instruments for the spring periods of 1993 and 1994 in the altitude range of 10–200 km and from –60° to 60° latitude for a local time of 12:00. The color bar indicates wind speeds from –80 to 80 m/s (positive northward). The prominent oscillations about the equator in the Mesosphere–Lower thermosphere (MLT) region are due to "atmospheric tides" driven by the daily change in solar heating. [Figure courtesy of Mark D. Burrage (deceased).]

Middle left. Variations in solar irradiance of Lyman α (121.6 nm) over about 11 years (late 1991 through the end of 2002) measured by the UARS (Solar Ultraviolet Spectral Irradiance monitor (SUSIM, in green) and Solar/Stellar Irradiance Comparison Experiment (SOLSTICE, in black) instruments. These ultraviolet flux measurements tracked the general solar irradiance decrease from a peak near the maximum of solar cycle 22 through a minimum in 1996 up to the maximum of solar cycle 23. Changes in solar irradiance at Lyman α from solar minimum to maximum are over 50%, a very substantial change. (Figure courtesy of Linton E. Floyd.)

Middle right. Chlorine monoxide (ClO) and ozone (O_3) in the Southern Hemisphere on 21 September 1991 (upper half of figure) and 20 September 1992 (lower half). The mapped quantities are vertical columns obtained by integrating the profiles retrieved from UARS Microwave Limb Sounder (MLS). High ClO amounts are indicated by the more brilliant red and purple colors. Low O_3 amounts are indicated by the more muted light blue and violet colors. The strong anti-correlation between high ClO and low O_3 indicates that the ClO is responsible for the O_3 destruction. (Figure courtesy of Joseph W. Waters.)

Far right. Time series of UARS Halogen Occultation Experiment (HALOE) global average hydrogen chloride (HCl) mixing ratio measurements (in parts per billion) at 55 km between late 1991 and 2005. The increases in HCl from late 1991 to 1997 were probably caused by increases in human-produced chlorofluorocarbon (CFC) gases. The decreases in HCl after 2001 were likely caused by international regulations limiting the production of CFC gases. Variations between 1997 and 2001 are not well understood at the present time. (Figure courtesy of James M. Russell, III.)

Dear Reader:

Welcome to the Laboratory for Atmospheres' 2005 Technical Highlights report. I thank you for your interest. We publish this report each year to describe our research and to summarize our accomplishments.

This document is intended for a broad audience. Our readers include colleagues within NASA, scientists outside the Agency, science graduate students, and members of the general public. Inside are descriptions of our organization and facilities, our major activities and science highlights, and our education and outreach accomplishments for calendar year 2005.

The Laboratory's approximately 230 scientists, technologists, and administrative personnel are part of the Earth–Sun Exploration Division in the Sciences and Exploration Directorate of the NASA Goddard Space Flight Center. The Laboratory for Atmospheres is continuing our mission of advancing knowledge and understanding of the Earth's atmosphere.

Laboratory scientists continued having a productive year organizing and participating in international field campaigns, developing and refining instruments, analyzing data, expanding data sets, and improving models. The Aura spacecraft, launched in July 2004, is an important component of the Lab's science activities through validation campaigns and data analysis and modeling. Aura has joined the complement of EOS satellites that is helping us better understand our home planet's environment, and is increasing our knowledge of the complex chemistry of the atmosphere.

We continued the very successful Distinguished Lecturer Seminar Series, which focused on precipitation, clouds, aerosols, and their physical/chemical linkages; details of the series can be found on our Web site.

As in previous years, Laboratory scientists garnered many top professional honors. The NASA Exceptional Achievement Medal was awarded to two lab members: Dr. Mian Chin for her development of the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model, and Dr. Yogesh Sud for his advances on land-surface parameterization and biospheric-atmospheric processes. Fritz Hasler, now retired from the Mesoscale Atmospheric Processes Branch, was awarded the Barry M. Goldwater award by the AIAA National Capitol Section for his education and outreach activities with the Electronic Theater (E-Theater). The IEEE elevated Chuck Cote to the grade of Senior Member, their highest professional grade. The Department of Energy (DOE) announced the selection of Dr. Warren Wiscombe as Chief Scientist for DOE's Atmospheric Radiation Measurement (ARM) program. In addition, there were several Group Achievement Awards. These were awarded to the Aura Education Outreach Team, the Aura Project Science Team, the SAGE Ozone Loss Validation Experiment (SOLVE)-II DC-8 Science Team, and the MODIS Aerosol Algorithm Team. A list of award winners is given in this report. I congratulate them for their outstanding achievements.

The year 2005 was also a time to bid farewell to several valuable members of the Laboratory. Dean Duffy, Fritz Hasler, Ernie Hilsenrath, Walt Hoegy, Larry Korb, Nathan Miller, Cuddapah Prabhakara, and Peter Wetzel retired. Marshall Shepherd left the Laboratory to become a professor at the University of Georgia and Bob Atlas is now with NOAA as director of The Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami.

I am pleased to greet new civil servants in the Laboratory, Peter Colarco, Christina Hsu, Ken Pickering, and Eric Wilcox.

Several noteworthy events took place during 2005. Two components of the Aura Validation Experiment (AVE) were successfully completed. The Polar AVE (PAVE) experiment was completed successfully from Pease Tradeport, New Hampshire on January 24, 2005. The experiment utilized the NASA DC-8, out of Dryden Flight Research Center. AVE Houston took place in June of 2005 from Ellington Field in Houston, Texas. The NASA WB-57 completed 8 successful science flights over the course of 14 days. Several Laboratory scientists were selected as investigators under the Instrument Incubator Program: Bruce Gentry (613.1), “Tropospheric Wind Lidar Technology Experiment” (TWiLiTE); Gerald Heymsfield (613.1), “High-Altitude Imaging Wind and Rain Airborne Profiler” (HIWRAP); David Whiteman (613.1), “Airborne Water, Aerosol, Cloud, and Carbon Dioxide Lidar”; Omar Torres (613.3/SSAI) Co-Investigator on “A High-Accuracy Spectropolarimetric Camera for Aerosol Remote Sensing from Space”; Warren Wiscombe (613.2), Collaborator with Langley Research Center (LaRC) investigators on “In-Situ Net Flux Within the Atmosphere of the Earth.” The Tropical Rainfall Measuring Mission (TRMM) was extended beyond its June 15 termination date. TRMM is expected to last until at least 2010, when the first of a series of planned follow-on Global Precipitation Measurement Mission (GPM) satellites is due to launch. The Upper Atmosphere Research Satellite (UARS) was retired from service on December 14 after making measurements of the upper atmosphere for more than 14 years. Scott Braun (613.1) was appointed Deputy Project Scientist for TRMM, and Joanne Joiner (613.3) was appointed Deputy Project Scientist for Aura.

This report is being published in two media: a printed version, and an electronic version on our Laboratory for Atmospheres Web site, http://atmospheres.gsfc.nasa.gov. Check out our Web site. It continues to be redesigned to be more useful for our scientists, colleagues, and the public. We welcome comments on this 2005 report and on the material displayed on our Web site; your comments may be submitted via the Web site.

Sincerely,

William K.-M. Lau,
Chief, Laboratory for Atmospheres, Code 613

April 2006

TABLE OF CONTENTS

PREFACE

The Technical Highlights for 2005 is the product of the efforts of all the members of the Laboratory for Atmospheres. Their dedication to advancing Earth Science through conducting research, developing and running models, designing instruments, managing projects, running field campaigns, and numerous other activities has produced many significant results. These can only be briefly highlighted in this report.

Production of this report has been guided by William K.–M. Lau, Chief of the Laboratory for Atmospheres who, along with Charles Cote, our Associate Chief, checked the report for accuracy, made suggestions regarding its content, and contributed to several sections. Walt Hoegy, editor for the past five years and now an emeritus member of the Laboratory, continued his association with this report by participating in teleconferences, and making valuable suggestions concerning the organization of this report and its content. Laura Rumburg gathered material for the Major Activities section, carefully proofread the report, and corrected many errors present in the initial drafts. Members of the administrative staff of the Laboratory and its branches: Jean Howard, Caroline Maswanganye, Marquita Harris, Pat Luber, and Cathy Newman were instrumental in gathering material for the report and soliciting the contributions of Lab members. Elaine Firestone performed the final editing and formatting, turning this report into a polished product in a timely manner.

The cover on this year's report recognizes the valuable contributions to Earth Science made by the Upper Atmosphere Research Satellite (UARS) over its 14 year life in orbit. The cover theme was suggested by Charles Cote. Charles Jackman, UARS project scientist, contributed the graphical components for the cover, the cover caption, and a special summary section on UARS in Section 5.

Finally, Goran Halusa, our Laboratory Web Master, created the final cover design and published this report on our Web site, http://atmospheres.gsfc.nasa.gov.

Richard W. Stewart

Mission: Advance Knowledge and Understanding of the Atmospheres of the Earth and Other Planets

1. INTRODUCTION

The Laboratory for Atmospheres (Code 613) is part of the Earth–Sun Exploration Division (Code 610) under the Sciences and Exploration Directorate (Code 600) based at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

In line with NASA's Exploration Initiative, the Laboratory executes a comprehensive research and technology development program dedicated to advancing knowledge and understanding of the atmospheres of the Earth and other planets. The research program is aimed at understanding the influence of solar variability on the Earth's climate; predicting the weather and climate of the Earth; understanding the structure, dynamics, and radiative properties of precipitation, clouds, and aerosols; understanding atmospheric chemistry, especially the role of natural and anthropogenic trace species on the ozone balance in the stratosphere and the troposphere; and advancing our understanding of physical properties of the Earth's atmospheres.

The research program identifies problems and requirements for atmospheric observations via satellite missions. Laboratory scientists conceive, design, develop, and implement ultraviolet, infrared, optical, radar, laser, and lidar technology for remote sensing of the atmosphere. Laboratory members conduct field measurements for satellite data calibration and validation, and carry out numerous modeling activities. These models include climate model simulations, modeling the chemistry and transport of trace species on regional to global scales, cloud resolving modes, and developing next-generation Earth system models. Interdisciplinary research is carried out in collaboration with other laboratories and research groups within the new Earth–Sun Exploration Division, as well as across the Sciences and Exploration Directorate.

The Laboratory for Atmospheres is a vital participant in NASA's research agenda. Our Laboratory often has relatively large programs, sizable satellite missions, or observational campaigns that require the cooperative and collaborative efforts of many scientists. We ensure an appropriate balance between our scientists' responsibility for these large collaborative projects and their need for an active individual research agenda. This balance allows members of the Laboratory to continuously improve their scientific credentials.

The Laboratory places high importance on promoting and measuring quality in its scientific research. We strive to ensure high quality through peer-review funding processes that support approximately 90% of the work in the Laboratory.

Members of the Laboratory interact with the general public to support a wide range of interests in the atmospheric sciences. Among other activities, the Laboratory raises the public's awareness of atmospheric science by presenting public lectures and demonstrations, by making scientific data available to wide audiences, by teaching, and by mentoring students and teachers. The Laboratory makes substantial efforts to attract new scientists to the various areas of atmospheric research. We strongly encourage the establishment of partnerships with Federal and state agencies that have operational responsibilities to promote the societal application of our science products.

This report describes our role in NASA's mission, gives a broad description of our research, and summarizes our scientists' major accomplishments during calendar year 2005. Please note that any seasonal references refer to those in the Northern Hemisphere. The report also contains useful information on human resources, scientific interactions, and outreach activities. This report is published in a printed version, and an electronic version on our Laboratory for Atmospheres Web site, http://atmospheres.gsfc.nasa.gov/.

2. STAFF, ORGANIZATION, AND FACILITIES

2.1 Staff

The diverse staff of the Laboratory for Atmospheres is made up of scientists, engineers, technicians, administrative assistants, and resource analysts, with a total staff of about 230.

The civil servant composition of the Laboratory consists of 59 members, plus 14 co-located members (4 resource analysts, 1 scientist, 1 project manager, 4 engineers, and 4 technicians). Of the 59 in-house civil servants, 49 are scientists, 2 are engineers, and 1 a technical manager. Of the 51 civil servant scientists and engineers, 90% hold doctoral degrees.

An integral part of the Laboratory staff is composed of onsite research associates and contractors. The research associates are primarily members of joint centers involving the Earth–Sun Exploration Division and nearby university associations (JCET[1], GEST[2], and ESSIC[3]), or are employed by universities with which the Laboratory has a collaborative relationship, such as George Mason University, University of Arizona, and Georgia Tech. Out of the 54 research associates, 91% hold Ph.D.'s. The onsite contractors are a very important component of the staffing of the Laboratory. Out of the total of 115 onsite contractors, 23% hold Ph.D.'s. The makeup of our Laboratory, therefore, is 26% civil servants, 24% associates, and 50% contractors.

The number of refereed publications (from 1991) and proposals (from 1997) written by laboratory members is shown in Figure 2.1. The number in each category is shown above the bars. Percentages in each category may be read from the ordinate. The difference between the yellow and red bars gives the number of papers that our scientists co-authored with outside scientists and is one measure of our extensive collaboration. The blue bars show the number of proposals written in recent years and indicate an increasing percentage as a function of papers written. The reduced number of refereed papers in 2004 and 2005 are due in part to the loss of the Atmospheric Experiment Branch, which is no longer part of our laboratory, to reduction in civil service scientists from attrition, and to the implementation of full cost accounting, which necessitates increased time spent on proposal writing.

[1] Joint Center for Earth Systems Technology
[2] Goddard Earth Sciences and Technology Center
[3] Earth System Science Interdisciplinary Center

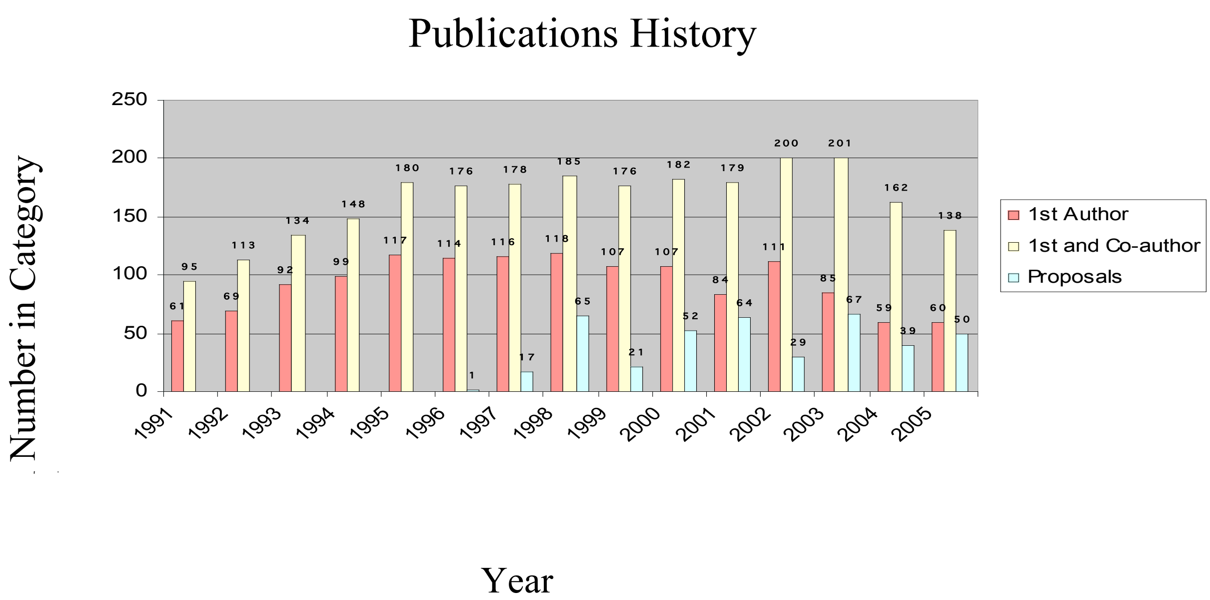


Figure 2.1. Number of proposals and refereed publications by Laboratory for Atmospheres members over the years. The yellow bar is the total number of publications where a Laboratory member is the first author or co-author, and the red bar is the number of publications where a Laboratory member is first author. Proposals written are shown in blue.

2.2 Organization

The management and branch structure for the Laboratory for Atmospheres at the end of 2005 is shown in Figure 2.2.

Senior Staff
William K. -M. Lau, Chief
Charles E. Cote, Associate Chief
Richard W. Stewart, Assistant Chief
Code 613

Senior Scientists
Robert F. Adler
Richard E. Hartle
Joel Susskind

Mesoscale Atmospheric Processes Branch
David O'C. Starr, Head
Code 613.1

Climate and Radiation Branch
Robert F. Cahalan, Head
Code 613.2

Atmospheric Chemistry and Dynamics Branch
P. K. Bhartia, Head
Code 613.3

Figure 2.2. Laboratory for Atmospheres organization chart at the end of calendar year 2005.

2.3 Branch Descriptions

The Laboratory has traditionally been organized into branches; however, we work on science projects that are becoming more and more cross-disciplinary. Branch members collaborate with each other within their branch, across branches, and across Divisions within the Directorate. Some of the recent cross-disciplinary research themes of interest in the Laboratory are the Global Water and Energy Cycle, Carbon Cycle, Weather and Short-Term Climate Forecasting, Long-Term Climate Change, Atmospheric Chemistry, and Aerosols. The employment composition of the Senior Staff Office (613) and the three branches is broken down by Civil Servant, Associate, and Contractor as shown in Figure 2.3.

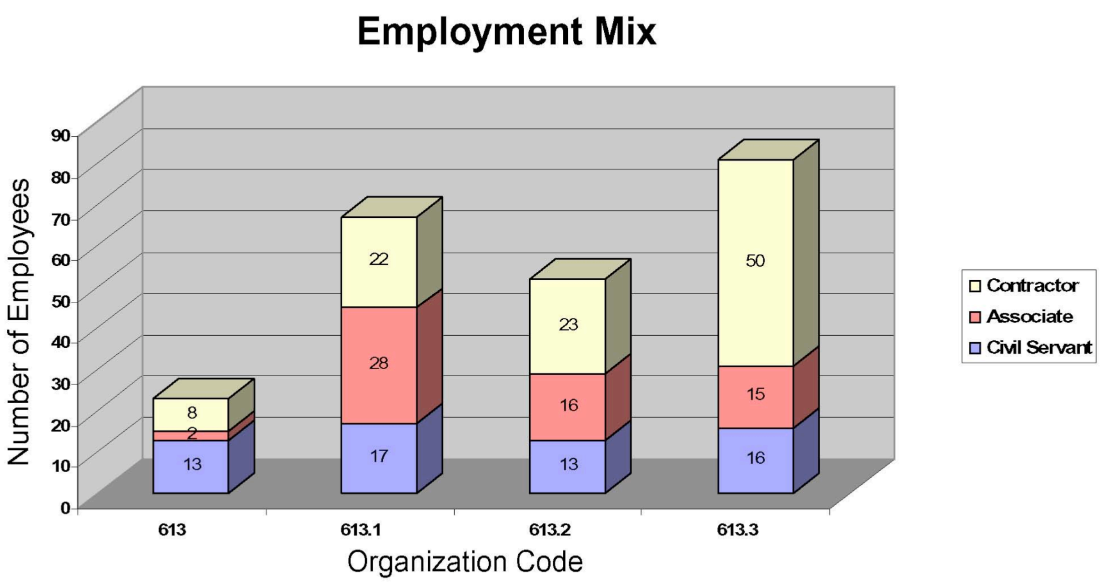


Figure 2.3. Employment composition of the members of the Laboratory for Atmospheres.

A brief description is given for each of the Laboratory's three branches. Later, in Section 5, the Branch Heads summarize the science goals and achievements of their branches. The branch summaries are supplemented by a selection of press releases, publication lists, and samples of highlighted journal articles given in Appendices 1 through 3, respectively.

Mesoscale Atmospheric Processes Branch, Code 613.1

The mission of this Branch is to understand the physics and dynamics of atmospheric processes through the use of satellite, airborne, and surface-based remote sensing observations and computer-based simulations. Development of advanced remote sensing instrumentation (primarily lidar) and techniques to measure meteorological parameters in the troposphere is an important focus. Key areas of investigation are cloud and precipitation systems and their environments, including aerosols, from the scale of individual clouds and thunderstorms to mesoscale convective systems and cyclonic storms, and their climate impacts at regional and global scales. The processes constituting the interaction of the atmosphere with the land and ocean surface are also of high priority. The Branch, therefore, focuses its research on all aspects of the atmospheric hydrologic cycle, its connections to the global energy cycle, and associated hazards. The Branch also seeks to contribute to the formulation of mission concepts to support planetary exploration, both measurements and modeling concerned with the assessment of meteorological hazards. Further information about Branch activities may be found on the Web at http://atmospheres.gsfc.nasa.gov/meso/.

Climate and Radiation Branch, Code 613.2

The Climate and Radiation Branch has a threefold mission:

(1) to understand, assess, and predict climate variability and change, including the impact of natural forcing and human activities on climate now and in the future;
(2) to assess the impacts of climate variability and change on society; and
(3) to consider strategies for adapting to, and mitigating, climate variability and change.

To address this mission, a wide-scale range is studied, from the microscale to the Sun–Earth distance in space, and from microsecond to geologic in time. Research focus areas include tropospheric aerosols, cloud processes, rainfall, solar radiation, and surface properties. Key disciplines are radiative transfer, both as a driver for climate change and as a tool for the remote sensing of parameters of the Earth's climate system; climate theory and modeling over the full range of scales; and the development of new methods for the analysis of climate data. Ongoing projects in cooperation with NASA partners address gaps in the current climate observing system, development and deployment of new instruments, and planning for future space-based and *in situ* missions. Further information about Branch activities may be found on the Web at http://climate.gsfc.nasa.gov/.

Atmospheric Chemistry and Dynamics Branch, Code 613.3

The Atmospheric Chemistry and Dynamics Branch conducts research on remote sensing of atmospheric trace gases and aerosols from satellite, aircraft, and ground, and develops computer-based models to understand and predict the long-term evolution of the ozone layer and changes in global air quality caused by human activity. Recent focus has been on understanding the interaction between atmospheric chemistry and climate change. The Branch develops and maintains research quality, long-term data sets of ozone, aerosols, and surface ultraviolet (UV) radiation for assessment of the health of the ozone layer and its environmental impact. It continues its long history of providing science leadership for NASA's atmospheric chemistry satellites, such as the Total Ozone Mapping Spectrometer (TOMS) and Upper Atmosphere Research Satellite (UARS), and the recently launched Earth Observing System (EOS) Aura satellite, and works closely with the National Oceanic and Atmospheric Administration (NOAA) on ozone sensors on the operational weather satellites (NOAA-N, the National Polar Orbiting Environmental Satellite System [NPOESS], and the NPOESS Preparatory Project [NPP]). The Aura satellite hosts four advanced atmospheric chemistry instruments designed to study the evolution of stratospheric ozone, climate, and air quality. Analysis of Aura data will be the central focus of the Branch activities in the coming years. Further information on Branch activities may be found on the Web http://atmospheres/gsfc.nasa.gov/acd/.

Branch Web sites may also be found by clicking on the branch icons at the Laboratory home page http://atmospheres.gsfc.nasa.gov/.

2.4 Facilities

Computing Capabilities

Computing capabilities used by the Laboratory range from high-performance supercomputers to scientific workstations to desktop personal computers. Each Branch maintains its own system of computers, which are a combination of Windows, Linux, and Mac OS X computers. The major portion of scientific data analysis and manipulation, and image viewing is still done on the cluster machines with increasing amounts of data analysis and imaging done on single-user personal computers.

Lidar

The Laboratory has well-equipped facilities to develop lidar systems for airborne and ground-based measurements of clouds, aerosols, methane, ozone, water vapor, pressure, temperature, and winds. Lasers capable of generating radiation from 266 nm to beyond 1,000 nm are available, as is a range of sensitive photon detectors for use throughout this wavelength region. Details may be found in the *Laboratory for Atmospheres Instrument Systems Report,* NASA/TP-2005-212783.

Radiometric Calibration and Development Facility

The Radiometric Calibration and Development Facility (RCDF) supports the calibration and development of instruments for ground- and space-based observations for atmospheric composition including gases and aerosols. As part of the EOS calibration program, the RCDF provides calibrations for all national and international ultraviolet and visible (UV/VIS) spaceborne solar backscatter instruments, which include the Solar Ultraviolet/Version 2 (SBUV/2) and TOMS instruments, and the European backscatter instruments flying on the Environmental Satellite (EnviSat) and Aura. The RCDF also provides laboratory resources for developing and testing of advanced spaceborne instruments being developed in the Laboratory for Atmospheres. In addition, ground-based sky-viewing instruments used for research and validation measurements of chemistry missions, such as Envisat and Aura, are also supported in the RCDF. The facility maintains state-of-the-art instrument radiometric test equipment and has a close relationship with the National Institute of Standards and Technology (NIST) for maintaining radiometric standards.

3. OUR RESEARCH AND ITS PLACE IN NASA'S MISSION

The direction of our research effort is influenced by NASA's overall program, outlined in the Agency's strategic plan of 2003, http://www.nasa.gov/pdf/1968main_strategi.pdf. The new vision for space exploration resulted in the transformation of NASA's goals and produced a reorganization of NASA Headquarters and the NASA Centers during 2004. The former seven strategic enterprises have been transformed into four components or mission offices: Exploration Systems, Space Operations, Science, and Aeronautics Research. Following NASA Headquarters, Goddard Space Flight Center has reorganized and formed one Directorate combining Earth and Space Science into the Sciences and Exploration Directorate. The three Divisions under the new Sciences and Exploration Directorate are Earth–Sun Exploration, Solar System Exploration, and Exploration of the Universe. The Laboratory for Atmospheres is under the Earth–Sun Exploration Division (ESED). Our three Branches, Mesoscale Atmospheric Processes, Climate and Radiation, and Atmospheric Chemistry and Dynamics will continue their strong programs of research in Earth Sciences and in this way, will make significant contributions to the President's Exploration Initiative. In October 2005, the Earth–Sun Exploration Division published a strategic plan for the Division outlining the Division's mission and goals in greater detail than the Agency plan http://webserv.gsfc.nasa.gov/images/esappdocs/ESEDstratplanv2.pdf. The Laboratory's research is guided by the goals contained in this plan. The remainder of this section outlines the connection of our research to NASA's mission and strategic plans.

The Laboratory for Atmospheres has a long history (40+ years) in Earth Science and Space Science missions studying the atmospheres of Earth and the planets. The wide array of our work reflects this dual history of atmospheric research:

(4) from the early days of the Television Infrared Observation Satellite (TIROS) and Nimbus satellites with emphasis on ozone, Earth radiation, and weather forecasting; and

(5) from the thermosphere and ionosphere satellites, the Orbiting Geophysical Observatory (OGO), the Explorer missions, and the Pioneer Venus Orbiter, to the more recent Galileo mission, and the current Cassini mission.

A current focus is on global climate change and one goal is to increase the accuracy and lead-time with which we can predict weather and climate change. The Laboratory for Atmospheres conducts basic and applied research in the cross-disciplinary research areas outlined in Table 3.1, and Laboratory scientists focus their efforts on satellite mission planning, instrument development, data analysis, and modeling.

Table 3.1: Science themes and our major research areas.

Science Themes	Major Research Areas
Aerosol Atmospheric Chemistry Carbon Cycle Climate Change Global Water and Energy Cycle Weather and Short-term Climate Forecasting	• Aerosol • Atmospheric Chemistry and Ozone • Atmospheric Hydrologic Cycle • Carbon Cycle • Clouds and Radiation • Climate Variability and Prediction • Mesoscale Processes • Precipitation Systems • Severe Weather • Chemistry-Climate Modeling • Global and Regional Climate Modeling • Data Assimilation

Our work can be classified into four primary activities or products: measurements, data sets, data analysis, and modeling. Table 3.2 depicts these activities and some of the topics they address.

Table 3.2: Laboratory for Atmospheres Science Activities.

Measurements	Data Sets	Data Analysis	Modeling
Aircraft Balloon Field campaigns Ground Space	Assimilated products Global precipitation MODIS[a] cloud and aerosol TOMS aerosol TOMS surface UV TOMS total ozone TOVS[b] Pathfinder TRMM[c] global precipitation products TRMM validation products	Aerosol cloud climate interaction Aerosol Atmospheric hydrologic cycle Climate variability and climate change Clouds and precipitation Global temperature trends Ozone and trace gases Radiation UV-B[d] measurements Validation studies	Atmospheric chemistry Clouds and mesoscale Coupled climate–ocean Data assimilation Data retrievals General circulation Radiative transfer Transport models Weather and climate

a. Moderate Resolution Imaging Spectroradiometer
b. TIROS Operational Vertical sounder
c. Tropical Rainfall Measuring Mission
d. Ultraviolet-B

Classification in the four major activity areas: measurements, data sets, data analysis, and modeling, is somewhat artificial, in that the activities are strongly interlinked and cut across science priorities and the organizational structure of the Laboratory. The grouping corresponds to the natural processes of carrying out scientific research: ask the scientific question, identify the variable needed to answer it, conceive the best instrument to measure the variable, generate data sets, analyze the data, model the data, and ask the next question.

4. MAJOR ACTIVITIES

The previous section outlined the science activities pursued in the Laboratory for Atmospheres. This section presents summary paragraphs of our major activities in measurements, field campaigns, data sets, data analysis, and modeling. In addition, we summarize the Laboratory's support for NOAA's remote sensing requirements. The section concludes with a listing of project scientists, and a description of interactions with other scientific groups.

4.1 Measurements

Studies of the atmosphere of Earth require a comprehensive set of observations, relying on instruments borne on spacecraft, aircraft, balloons, or those that are ground-based. Our instrument systems 1) provide information leading to basic understanding of atmospheric processes, and 2) serve as calibration references for satellite instrument validation.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations. Airborne instruments provide critical *in situ* and remote measurements of atmospheric trace gases, aerosol, ozone, and cloud properties. Airborne instruments also serve as stepping-stones in the development of spaceborne instruments, and serve an important role in validating spacecraft instruments.

Table 4.1 shows the principal instruments that were built in the Laboratory, or for which a Laboratory scientist has had responsibility as Instrument Scientist. The instruments are grouped according to the scientific discipline each supports. Table 4.1 also indicates each instrument's deployment—in space, on aircraft, balloons, on the ground, or in the laboratory. In most cases, details are presented in a separate Laboratory technical publication, the *Instrument Systems Report,* NASA/TP-2005-212783. Exceptions are the Unmanned Aerial Vehicle (UAV) Radar (URAD), High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP), and CO_2 lidar for which recent developments are described in Section 5.4.

Table 4.1: Principal instruments supporting scientific disciplines in the Laboratory for Atmospheres.

	Atmospheric Structure and Dynamics	**Atmospheric Chemistry**	**Clouds and Radiation**
Space		Total Ozone Mapping Spectrometer (TOMS) Earth Polychromatic Imaging Camera (EPIC)	
Aircraft/Balloon	ER-2 Doppler Radar (EDOP) Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) Air Goddard Lidar Observatory for Winds (Air GLOW) UAV Radar (URAD) High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)	Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTAL) Raman Airborne Spectroscopic Lidar (RASL) Airborne Compact Atmospheric Mapper (ACAM)	Cloud Physics Lidar (CPL) cloud THickness from OffbeamReturns (THOR) Lidar Cloud Radar System (CRS) Unmanned Aerial Vehicle Cloud Physics Lidar (UAV CP Lidar)

Ground/ Laboratory/ Development	Scanning Raman Lidar (SRL) Goddard Lidar Observatory for Winds (GLOW) Lightweight Rain Radiometer-X band (LRR-X)	Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE) Aerosol and Temperature Lidar (AT Lidar) Brewer UV Spectrometer Kiritimati Island Lidar Trailer (KILT) Lagrange-2 Solar Viewing Interferometer Prototype (L2-SVIP) Instrument Incubator Program (IIP) GeoSpec (IIP) CO_2 Lidar	Micro-Pulse Lidar (MPL) COmpact Visible Infrared Radiometer (COVIR) Surface-Sensing Measurements for Atmospheric Radiative Transfer (SMART)—Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere (COMMIT)

4.2 Field Campaigns

Field campaigns use the resources of NASA, other agencies, and other countries to carry out scientific experiments, to validate satellite instruments, or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2, DC-8, and WB-57F serve as platforms from which remote sensing and *in situ* observations are made. Ground-based systems are also used for soundings, remote sensing, and other radiometric measurements. In 2005, Laboratory personnel supported many such activities as scientific investigators, or as mission participants, in the planning and coordination phases.

Aura Validation Experiment (AVE)

AVE is a measurement campaign designed to acquire correlative data needed for the validation of the Aura satellite instruments. Aura was launched in July 2004 with four instruments: OMI, TES, MLS, and the High Resolution Dynamics Limb Sounder (HIRDLS). Aura has three science objectives: 1) analyze the recovery of the ozone layer, 2) assess air quality problems, and 3) determine how the Earth's climate is changing.

There have been three AVE missions flown since the Aura launch. The first AVE campaign was flown from NASA's Johnson Space Center (JSC) Ellington Field in October–November 2004 on the high altitude NASA WB-57F aircraft. The second AVE (the Polar Aura Validation Experiment, PAVE) campaign was flown from Portsmouth, New Hampshire, in January 2005 on the long range NASA DC-8 aircraft. The third campaign was also flown from Ellington Field in June 2005 on the high altitude NASA WB-57F aircraft. Eight successful science flights were completed over the course of 14 days.

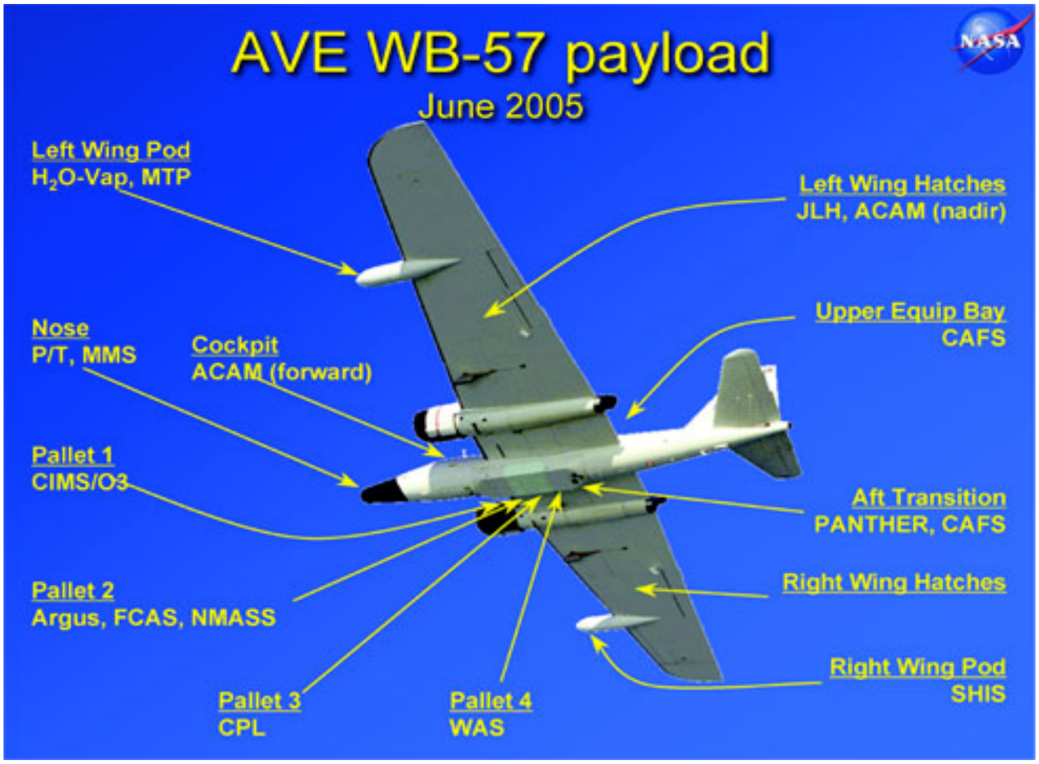


Figure 4.1. Instrument locations on the WB-57 for the AVE Houston campaign.

Laboratory members participating in this mission were Paul Newman (613.3, Project Scientist), Scott Janz (613.3, ACAM Principal Investigator [PI]), Kent McCullough (ACAM and Argus Team/SSAI), Rich McPeters (613.3, Aura/OMI Co-PI), Matt McGill (613.1, CPL PI), Dennis Hlavka (613.1/SSAI, CPL Team), William Hart (613.1/SSAI, CPL Team), and Leslie Lait (613.3/SSAI, Met. Team). For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov). More information may be found at the Aura Web site: http://aura.gsfc.nasa.gov/ and the Aura Validation Data Center site: http://avdc.gsfc.nasa.gov/Overview/news.html.

A fourth AVE is scheduled to be flown from San Jose, Costa Rica in January–February 2006 on the high altitude NASA WB-57F aircraft.

Polar Aura Validation Experiment (PAVE)

The Polar Aura Validation Experiment (PAVE), one of a number of Aura validation experiments, is a NASA international science mission to acquire critical high quality measurements of the polar region in support of the recently launched Aura satellite. PAVE is the third of a series of Aura validation missions designed to provide correlative measurements to help understand the transport of gases and aerosols in the troposphere and their exchange with the lower stratosphere. The PAVE experiment was completed successfully from Pease Tradeport, New Hampshire, in January 2005. The experiment utilized the NASA DC-8, based at Dryden Flight Research Center (DFRC.). Included in these flights was AROTAL, which made measurements of O_3, temperature, and aerosol profiles. The AROTAL team on this mission consisted of Tom McGee (613.3, PI), Walt Hoegy (613, Emeritus), Don Silbert (613.3), Grant Sumnicht (613.3/Science Systems and Application, Inc. [SSAI]), and Larry Twigg (613.3/SSAI). The project scientists are Mark Schoeberl (NASA Goddard Space Flight Center [GSFC]) and Eric Jensen (NASA Ames Research Center [ARC)]. For more information contact Tom McGee (Thomas.J.McGee@nasa.gov) or Mark Schoeberl (Mark.R.Schoeberl@nasa.gov). More information may be found at the PAVE Web site: http://cloud1.arc.nasa.gov/ave-polar/.

CPL Activities

During 2004, the CPL was modified to operate on the NASA WB-57F aircraft. Historically, the CPL operated only on the ER-2 aircraft. Future missions, however, will require use of the WB-57F, so it became imperative to adapt CPL to that aircraft. Mechanical, thermal, and data system modifications were required for operation on the WB-57F. After modifications were made, the CPL participated in the first AVE conducted from Ellington Field in Houston, Texas from October 18 to November 12, 2004. The purpose of this experiment was to validate the instruments onboard the Aura satellite. A total of nine satellite underflights was performed under a variety of atmospheric conditions.

In June 2005, the CPL participated in the second AVE, also conducted from Ellington Field. The NASA WB-57F completed eight successful science flights over the course of 14 days.

For more information on the CPL instrument, or for access to CPL data, visit http://cpl.gsfc.nasa.gov/, or contact Matthew McGill (matthew.j.mcgill@nasa.gov).

Airborne Compact Atmospheric Mapper (ACAM)

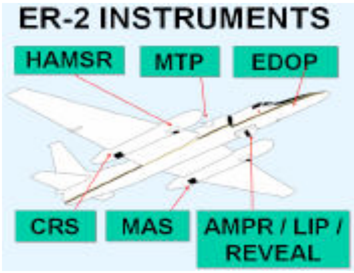
A new aircraft based measurement program was started in 2005. ACAM was test flown onboard the NASA WB57F during AVE in June of 2005 flying out of Houston, Texas. This new system, developed in the RCDF, combines high resolution photographic imagery of both nadir and forward looking cloud conditions with nadir UV and VIS spectrographic measurements in order to map trace gas concentrations of nitrogen dioxide, ozone, and aerosols. These measurements will be used to validate similar measurements from the Ozone Monitoring Instrument (OMI) onboard Aura. The test flights were successful and led to instrument improvements that will be implemented for the Costa Rica AVE (CR-AVE) mission in February of 2006.

For more information contact Scott Janz (Scott.Janz@nasa.gov) or Paul Newman (Paul.A.Newman@nasa.gov), or visit the Web site at (http://code916.gsfc.nasa.gov/Public/Ground_based/acam/acam.html.

Tropical Cloud Systems and Processes (TCSP)

The Tropical Cloud Systems and Processes (TCSP) mission is an Earth science field research investigation sponsored by NASA's Science Mission Directorate. The field phase was conducted during the period July 1–27, 2005 out of the Juan Santa Maria Airfield in San Jose, Costa Rica. The TCSP field experiment flew 12 NASA ER-2 science flights, including missions to Hurricanes Dennis and Emily, Tropical Storm Gert, and an eastern Pacific mesoscale complex that may possibly have further developed into Tropical Storm Eugene. The P-3 aircraft from the NOAA Hurricane Research Division (HRD) flew 18 coordinated missions with the NASA research aircraft to investigate developing tropical disturbances. Additionally, the aerosonde Uninhabited Aerial Vehicle (UAV) flew eight surveillance missions and the *Instituto Meteorologico Nacionale* (IMN) of Costa Rica launched RS-92 balloon sondes daily to gather humidity measurements and provide validation of the water vapor measurements.

TCSP is focused on the study of the dynamics and thermodynamics of precipitating cloud systems and tropical cyclones using NASA-funded aircraft and surface remote sensing instrumentation. Targeted data sets were collected using the NASA ER-2 research aircraft, in synergy with other surface and airborne remote sensing observations provided by NASA and other agencies. These observations will be used to



answer key questions pertaining to the origins and lifecycle of weather disturbances in the tropics. Analyses of data sets will address a wide variety of atmospheric space and time scales, ranging from the convective through the synoptic. Investigations will also be conducted to improve upon numerical modeling studies of tropical cyclogenesis, including wave-to-depression transition in the western Caribbean, Gulf of Mexico, and eastern Pacific Ocean.

TCSP research addresses the following topical areas: 1) tropical cyclone structure, genesis, intensity change, moisture fields and rainfall; 2) satellite and aircraft remote sensor data assimilation and validation studies pertaining to development of tropical cyclones; and 3) the role of upper tropospheric/lower stratospheric processes governing tropical cyclone outflow, the response of wave disturbances to deep convection, and the evolution of the upper level warm core.

The TCSP experiment builds upon the success of the previous Convection and Moisture Experiment (CAMEX) missions. For further information contact Gerald Heymsfield (Gerald.M.Heymsfield@nasa.gov) or visit the TCSP Web site at http://camex.msfc.nasa.gov/tcsp/.

4.3 Data Sets

In the previous discussion, we examined the array of instruments and some of the field campaigns that produce the atmospheric data used in our research. The raw and processed data from these instruments and campaigns are used directly in scientific studies. Some of this data, plus data from additional sources, is arranged into data sets useful for studying various atmospheric phenomena. The major data sets are described in the following paragraphs.

50-Year Chemical Transport Model (CTM) Output

A 50-year simulation of stratospheric constituent evolution has been completed using the Code 613.3 three-dimensional (3-D) chemistry and transport model. Boundary conditions were specified for chlorofluorocarbons, methane, and N_2O appropriate for the period 1973–2023. Sulfate aerosols were also specified, and represent the eruptions of El Chichón and Mt. Pinatubo. Simulations with constant chlorine (1979 source gases) and low chlorine (1970 levels) and without the volcanic aerosols have also been completed to help distinguish chemical effects from effects of both interannual variability and a trend in the residual circulation in the input meteorological fields. The model output from all simulations is available on the Code 613.3 science system; software to read the output is also available. Although the CTM itself is run at $2° \times 2.5°$ latitude/longitude horizontal resolution; the output is stored at $4° \times 5°$ latitude/longitude. Higher resolution files are available from UniTree, the Code 606.2 archive. The model output stored on the science system is for 6 days each month (1, 5, 10, 15, 20, 25); daily fields are saved on UniTree. Details about this and other CTM simulations are available from the Code 613.3 Web site at http://code916.gsfc.nasa.gov/Public/Modelling/3D/exp.html, which shows model runs made in 2005. Questions or comments should be addressed to Anne Douglass (Anne.R.Douglass@nasa.gov).

Near-UV Aerosol Products from TOMS and OMI

The near-UV technique of aerosol characterization differs from conventional visible and near-IR methods in that the UV measurements can separate UV-absorbing aerosol (such as desert dust, smoke from biomass burning, and volcanic ash) from nonabsorbing aerosol (such as sulfates, sea salt, and ground-level fog). In addition, the UV technique can detect aerosol over water and land surfaces, including deserts, where traditional visible (VIS) and near-infrared (IR) methods do not work. TOMS aerosol data are currently available in the form of a contrast index and as near-ultraviolet (UV) extinction optical depth. The science value of the TOMS aerosol information has been enhanced by the application of an inversion procedure to the TOMS measured radiances to derive the near-UV extinction optical depth and single-scattering albedo of aerosol. Satellite-derived single scattering albedo from TOMS observations for biomass burning episodes was evaluated by comparison to the Aerosol Robotic Network (AERONET) ground based retrievals. The evaluation indicates that the TOMS and AERONET single-scattering albedo products are in agreement within 0.03 in most cases.

The record of Aerosol Index and near-UV aerosol properties will be extended into the future making use of observations by the Ozone Monitoring Instrument (OMI) on the Aura spacecraft, launched on July 2004. The figure below shows a 4-day sequence of a Saharan dust outbreak in March 2005 as seen by OMI. For more information contact Omar Torres (torres@tparty.gsfc.nasa.gov).

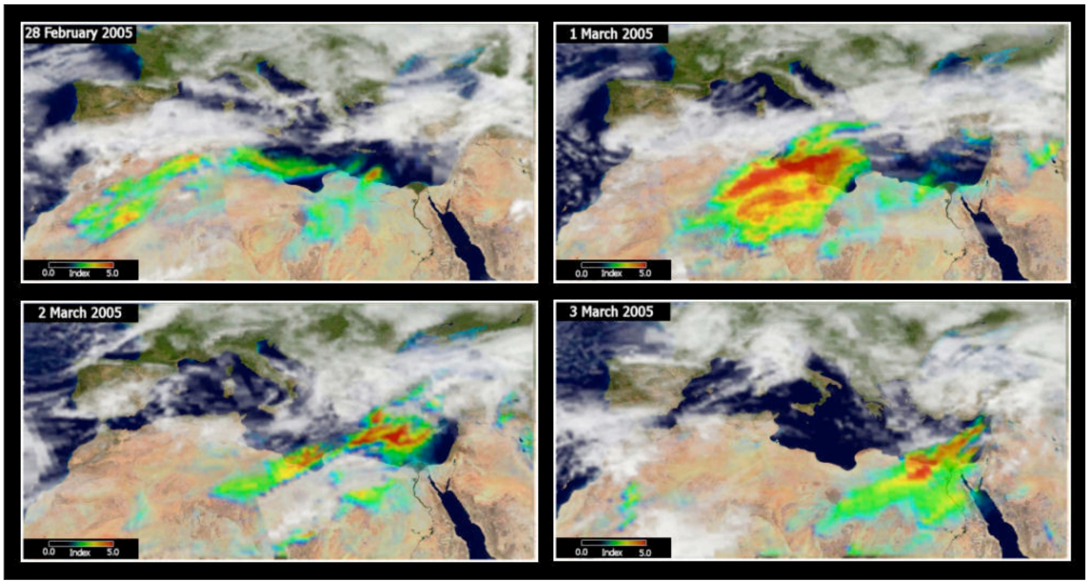


Figure 4.2. Saharan dust aerosols as seen by the Aura-OMI sensor Aerosol Index. The aerosol detection capability in the presence of clouds is a unique advantage of the OMI and TOMS observations.

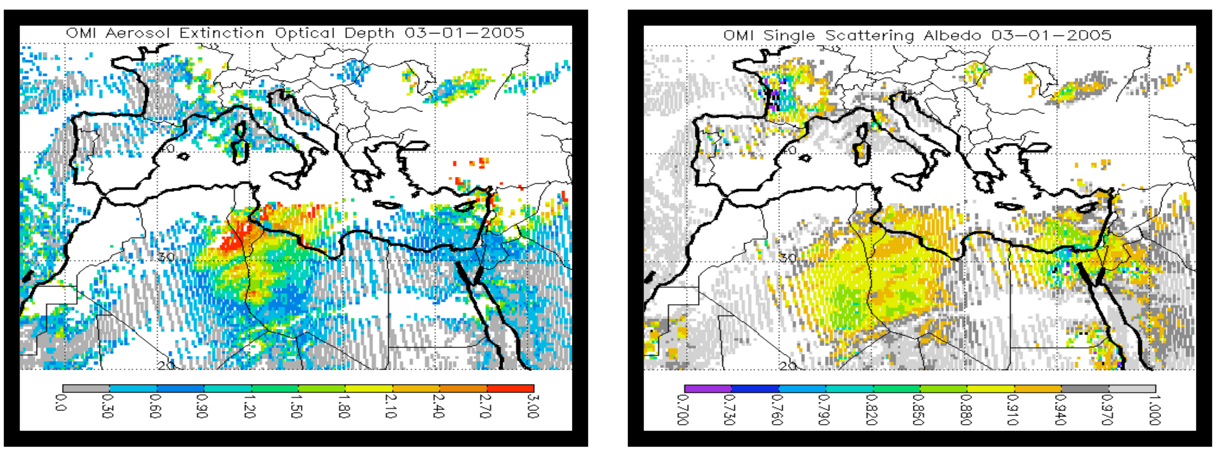


Figure 4.3. OMI retrievals of aerosol extinction optical; depth (left), single scattering albedo (right), during a Saharan dust outbreak on March 1, 2005.

Global Precipitation

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing climatic fluctuations and trends on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) has established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory are leading the GPCP effort to merge data from both low-Earth orbit satellites and geosynchronous satellites, and ground-based rain gauges, to produce research-quality estimates of global precipitation.

The GPCP data set provides global, monthly precipitation estimates for the period January 1979 to the present. Updates are being produced on a quarterly basis. The release includes input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at NOAA's National Climatic Data Center in Asheville, North Carolin,a and at the Goddard Distributed Active Archive Center (DAAC). Evaluation is ongoing for this long-term data set in the context of climatology, El Niño Southern Oscillation (ENSO)-related variations, and regional and global trends. The eight-year TRMM data set is being used in the assessment of the longer GPCP data set. A daily, globally complete analysis of precipitation is also being produced by Laboratory scientists for GPCP for the period 1997 to the present and is available from the archives.

An even finer time resolution, a TRMM-based quasi-global, 3-hour resolution rainfall analysis, the TRMM Multi-satellite Precipitation Analysis (TMPA) is available from the Goddard DAAC for the period of January 1998 to the present. This product uses TRMM data to calibrate or adjust rainfall estimates from other satellite data and combines these estimates into rainfall maps at a frequency of every 3 hours. A real-time version of this analysis is available through the TRMM Web site. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Merged TOMS/SBUV Data Set

We have recently updated our merged satellite total ozone data set through late 2005. We have transferred the calibration from the original six satellite instruments to the current instrument NOAA 16 SBUV/2. We also have a merged profile data set from the SBUV instruments. The data, and information about how they were constructed, can be found at http://code916.gsfc.nasa.gov/Data_services/merged. It is expected that these data will be useful for trend analyses, for ozone assessments, and for scientific studies in general. During 2006, we will incorporate the data from the OMI instrument on Aura. For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov) or Stacey Frith (smh@code916.gsfc.nasa.gov).

Moderate Resolution Imaging Spectroradiometer (MODIS)

Operational MODIS data includes both level-2 and level-3 products. There are six categories of level-2 (pixel-level or swath data) MODIS Atmosphere products collected from two platforms: Terra and Aqua. There are three level-3 (global gridded) MODIS Atmosphere Products produced from each platform. Each of the level-3 products contains statistics generated from the first four level-2 products noted below.

The level-2 product files are grouped by Aerosol, Water Vapor, Cloud, Atmospheric Profile, and Cloud Mask geophysical retrievals. In addition, the Joint Atmosphere Product contains a spatial sample of the more popular atmospheric retrievals. Level-3 MODIS Atmosphere products provide statistics on a 1° × 1° global grid and are produced for daily, eight-day, and monthly time periods.

Level-2 Products

The *Aerosol Product* provides aerosol optical thickness over the oceans globally and over a portion of the continents. Further, information regarding the aerosol size distribution is derived over the oceans, while the aerosol type is derived over continents. Level-2 aerosol retrievals are at the spatial resolution of a 10×10, 1 km (at nadir) pixel array.

The *Precipitable Water Product* consists of two-column water vapor retrievals. During the daytime, a near-infrared algorithm is applied over clear land areas, ocean sun glint areas, and above clouds over both land and ocean. An infrared algorithm used in deriving atmospheric profiles is also applied both day and night.

The *Cloud Product* combines infrared and visible techniques to determine both physical and radiative cloud properties. Cloud optical thickness, effective particle radius, and water path are derived at a 1 km resolution using MODIS visible through mid-wave infrared channel observations. Cloud-top temperature, pressure, and effective emissivity are produced by infrared retrieval methods, both day and night, at a 5×5, 1 km pixel resolution. Cloud thermodynamic phase is derived from a combination of techniques and spectral bands. Finally, the MODIS Cloud Product includes an estimate of cirrus reflectance in the visible at a 1 km pixel resolution; these retrievals are useful for removing cirrus scattering effects from the land-surface reflectance product.

The *Atmospheric Profile Product* consists of several parameters: total column ozone, atmospheric stability, temperature and moisture profiles, and atmospheric water vapor. All of these parameters are produced day and night at a 5×5, 1 km pixel resolution when a 5×5 region is suitably cloud free.

The *Cloud Mask Produc*t indicates to what extent a given instrument field of view (FOV) of the Earth's surface is unobstructed by clouds. The cloud mask also provides additional information about the FOV, including the presence of cirrus clouds, ice/snow, and sun glint contamination.

The *Joint Atmosphere Product* contains a subset of key parameters gleaned from the complete set of operational level-2 products: Aerosol, Water Vapor, Cloud, Atmospheric Profile, and Cloud Mask. The Joint Atmosphere product was designed to be small enough to minimize data transfer and storage requirements, yet robust enough to be useful to a significant number of MODIS data users. Scientific data sets (SDSs) contained within the Joint Atmosphere Product cover a full set of high-interest parameters produced by the MODIS Atmosphere Group, and are stored at 5 km and 10 km (at nadir) spatial resolutions.

Level-3 Products

The Level-3 MODIS *Atmosphere Daily Global Product* contains roughly 600 statistical data sets, which are derived from approximately 80 scientific parameters from four Level-2 MODIS Atmosphere Products: Aerosol, Water Vapor, Cloud, and Atmospheric Profile. Statistics are sorted into 1° × 1° cells on an equal-angle grid that spans 24 hours (0000 to 2400 UTC). A range of statistical quantities is computed, depending on the parameter being considered. In addition to simple statistics, the level-3 files include a variety of one- and two-dimensional histograms. Similarly, the level-3 *Eight-Day* and *Monthly Global Product* contain roughly 800 statistical data sets that are derived from the level-3 *Daily* and *Eight-Day* products, respectively.

For further information, contact Steven Platnick (Steven.Platnick@nasa.gov) or visit the MODIS Web site at http://modis-atmos.gsfc.nasa.gov/. Discussion of the MODIS data processing is contained in Section 5 of this report.

MPLNET Data Sets

The Micro-Pulse Lidar Network (MPLNET) is composed of ground-based lidar systems co-located with sun-sky photometer sites in the NASA AERONET. The MPLNET project uses the MPL system, a compact and eye-safe lidar capable of determining the range of aerosols and clouds continuously in an autonomous fashion. The unique capability of this lidar to operate unattended in remote areas makes it an ideal instrument to use for a network. The primary purpose of MPLNET is to acquire long-term observations of aerosol and cloud vertical structure at key sites around the world. These types of observations are required for several NASA satellite validation programs, and are also a high priority in the Third Assessment Report of the Intergovernmental Panel on Climate

Change (IPCC). The combined lidar and sun photometer measurements are able to produce quantitative aerosol and cloud products such as optical depth, sky radiance, vertical structure, and extinction profiles.

MPLNET results have contributed to studies of dust, biomass, marine, and continental aerosol properties, the effects of soot on cloud formation, aerosol transport processes, and polar clouds and snow. MPLNET sites served as ground calibration/validation for NASA's first satellite lidar, the Geoscience Laser Altimeter System (GLAS), and will also provide validation for the next satellite lidar, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). MPLNET data has also been used to validate results from passive NASA satellite sensors such as MODIS, the Multi-Angle Imaging Spectroradiometer (MISR), and TOMS.

The MPLNET project underwent a major expansion in 2005. There are currently 10 active sites in the network: three in the U.S., three in Asia, two in Antarctica, one in the Arctic, and one off the west coast of Africa. Data from several of the sites are already publicly available on our Web site, and the remaining sites will soon be public after the calibrations are completed (data is being acquired offline in the interim). Older data sets from an additional 14 sites remain available as well. Planning is underway for future sites in 2006, including additional sites in the U.S., Asia, the west coast of Africa, and new sites in the Caribbean, South America, and the Middle East.

Further information on the MPLNET project, and access to data, may be obtained online at http://mplnet.gsfc.nasa.gov. For questions on the MPLNET project, contact Judd Welton (Judd.Welton@nasa.gov).

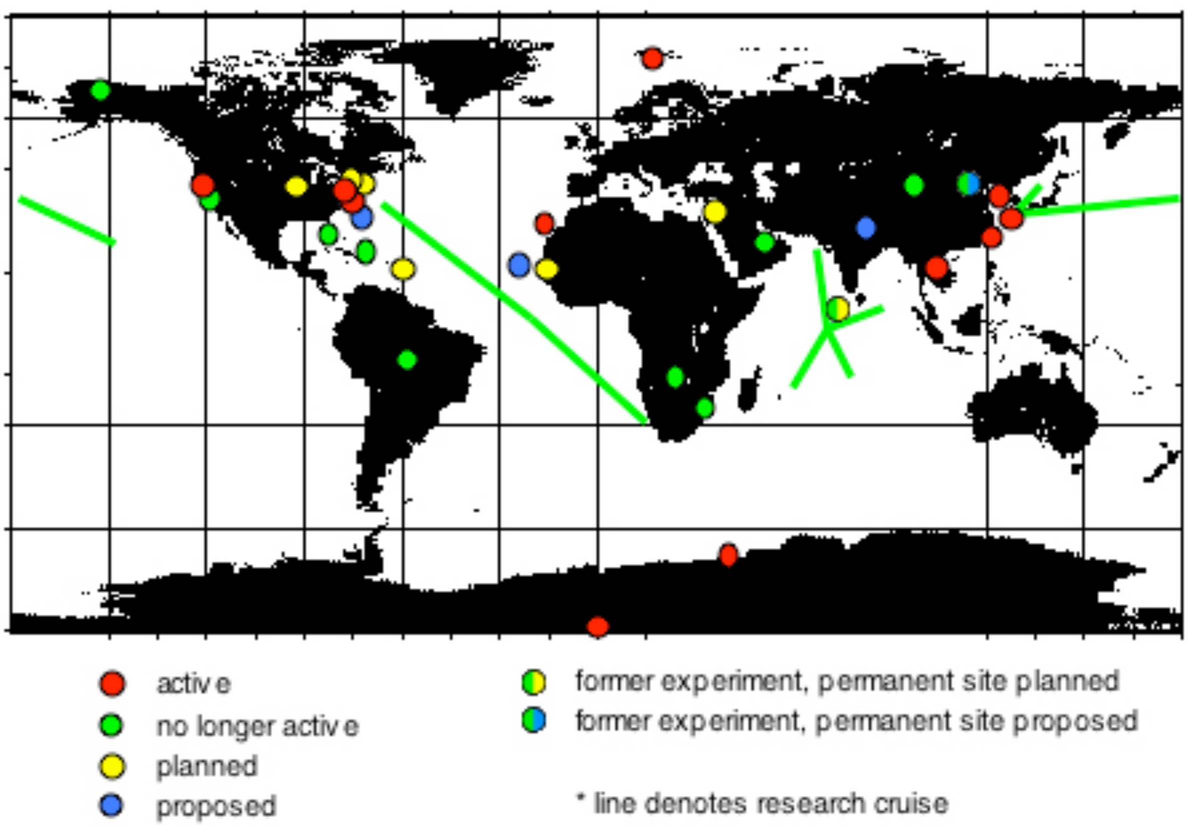


Figure 4.4. MPLNET sites

Skyrad Ground-Based Observations

Skyrad, a ground-based measurement program to observe the zenith sky, continues to investigate radiative transfer properties of the atmosphere in the near-UV and visible (300–500 nm). The purpose of these observations is to test the accuracy of the Laboratory's highly regarded radiative transfer models, to improve ozone algorithms (for both ground and space), and to validate orbiting satellite instruments, which also operate in this wavelength range. There are now several U.S. and international instruments in orbit (Aura, TOMS, and EnviSat) operating in this wavelength range. The observations are taken from the Laboratory's RCDF, which houses several ground-based instruments, notably the Shuttle Solar Backscatter Ultraviolet (SSBUV) and a double monochromator Brewer instrument. This location is ideally suited for these studies because several instruments measuring aerosols (AERONET and sun photometers) are located near the RCDF.

Nearly three years of zenith sky data have been taken over a range of sky conditions using SSBUV. In addition, an accurate set of tables of expected zenith sky radiances was calculated for conditions over Goddard, including a range of aerosol characteristics and ozone amounts. Comparisons of observations and models resulted in differences of less than 3%. The zenith data are also being used to derive ozone column amounts and aerosol characteristics in the ultraviolet at high solar zenith angles. Accurate ground-based measurements of ozone under these conditions are desperately needed for validation of satellite data. Errors in satellite observation are largest at high solar zenith angles, a critical region for observing ozone trends. The GSFC Brewer monochromator has been modified and further calibrated to measure, in addition to ozone, nitrogen dioxide, sulfur dioxide, and the absorbing properties of aerosols, which is a new application for this instrument. These measurements are being proposed for local air-quality observations and for validating the OMI flying on Aura, as well as similar instruments flying on European satellites. For more information, contact Scott Janz (Scott.Janz@nasa.gov) or Jay Herman (Jay.R.Herman@nasa.gov).

TIROS Operational Vertical Sounder (TOVS) Pathfinder

The Pathfinder Projects are joint NOAA–NASA efforts to produce multiyear climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is TOVS. TOVS is composed of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 until April 2005, when NOAA 14 stopped transmitting data We used an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The TOVS Pathfinder Path A data set covers the period 1979–2004 and consists of global fields of surface skin and atmospheric temperatures, atmospheric water vapor, cloud amount, cloud height, Outgoing Longwave Radiation (OLR), clear sky OLR, and precipitation estimates. The data set includes data from TIROS N, and NOAA 6, 7, 8, 9, 10, 11, 12, and 14. Equivalent future data sets will be produced from Atmospheric Infrared Sounder (AIRS) data on EOS Aqua. We have demonstrated with the 25-year TOVS Pathfinder Path A data set that TOVS data can be used to study interannual variability, trends of surface and atmospheric temperatures, humidity, cloudiness, OLR, and precipitation. The TOVS precipitation data are being incorporated in the monthly and daily GPCP precipitation data sets.

We have also developed the methodology used by the AIRS science team to generate products from AIRS for weather and climate studies, and continue to improve the AIRS science team retrieval algorithm. A new algorithm, Version 4.0, was recently delivered to NASA's Jet Propulsion Laboratory (JPL.) The Goddard DAAC has been producing AIRS level-2 soundings since September 2002 using an early version of the AIRS science team retrieval algorithm. The DAAC began producing improved AIRS level-2 soundings starting in April 2005 based on the Version 4.0 AIRS Science Team retrieval algorithm. All products obtained in the TOVS Pathfinder data set will also be produced from AIRS, including precipitation estimates. In joint work with Robert Atlas, AIRS temperature profiles derived using this improved retrieval algorithm have been assimilated into the Laboratory forecast analysis system and have shown a significant improvement in weather prediction skill. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

TOMS and OMI Data Sets

Since the Atmospheric Chemistry and Dynamics Branch first formed, it has been tasked with making periodic ozone assessments. Through the years the Branch has led the science community in conducting ozone research by making measurements, analyzing data, and modeling the chemistry and transport of trace gases that control the behavior of ozone. This work has resulted in a number of ozone and related data sets based on the TOMS instrument. The first TOMS instrument flew onboard the Nimbus-7 spacecraft and produced data for the period from November 1978 through May 6, 1993 when the instrument failed. Data are also available from the Meteor-3 TOMS instrument (August 1991–December 1994) and from the TOMS flying on the Earth Probe (EP-TOMS) spacecraft (July 1996–present).

TOMS data are given as daily files of ozone, reflectivity, aerosol index, and erythemal UV flux at the ground. A new Version 8 algorithm was released in 2004, which addresses errors associated with extreme viewing conditions. These data sets are described on the Atmospheric Chemistry and Dynamics Branch Web site, which is linked to the Laboratory Web site, http://atmospheres.gsfc.nasa.gov/. Click on the "Code 613.3" Branch site, and then click on "Data Services." The TOMS spacecraft and data sets are then found by clicking on "TOMS Total Ozone data." Alternatively, TOMS data can be accessed directly from http://toms.gsfc.nasa.gov.

Very similar data are being produced by the OMI instrument on the recently launched Aura spacecraft and are also available from the TOMS Web site http://toms.gsfc.nasa.gov. Because of calibration problems with the aging EP-TOMS instrument, OMI data should be used in preference to TOMS data beginning in 2005.

Tropospheric O_3 Studies

In 2005, new Aura satellite ozone measurements from the OMI and Microwave Limb Sounder (MLS) were used to develop global maps of tropospheric ozone. Day-to-day tropospheric ozone maps from OMI/MLS were processed for more than one year beginning in August 2004. OMI/MLS tropospheric ozone data were validated from ground-based and other satellite-based measurements. Evaluation of OMI/MLS tropospheric ozone shows evidence of a one-to-two month Madden-Julian Oscillation (MJO) in the tropical Pacific. The data also indicate enhancements in tropospheric ozone over Indonesia during November 2004, which coincided with a weak tropical El Niño event. Features in summer months include an accumulation of tropospheric ozone over the broad Mediterranean region as suggested in past modeling studies. General features (e.g., seasonal cycles, spatial patterns) in tropospheric ozone from OMI/MLS compared well with both NCAR's Model for Ozone and Related Chemical Tracers (MOZART-2) and Goddard's GMI CTM modeled tropospheric ozone. Daily maps of tropospheric ozone from OMI/MLS have been evaluated and further tested for the application of tracking global pollution events. The new tropospheric ozone maps from OMI/MLS have been shown at many national and international science meetings by both modelers and nonmodelers within Code 613.3 (Atmospheric Chemistry and Dynamics Branch). For more information contact Jerry Ziemke (Jerald.R.Ziemke.1@gsfc.nasa.gov).

4.4 Data Analysis

A considerable effort by our scientists is spent in analyzing the data from a vast array of instruments and field campaigns. This section details some of the major activities in this endeavor.

Aerosol and Water Cycle Dynamics

Aerosol can influence the regional, and possibly the global, water cycle by changing the surface energy balance, modifying cloud microphysics, and altering cloud and rainfall patterns. On the other hand, condensation heating from rainfall, and radiative heating from clouds and water vapor associated with fluctuations of the water cycle, drive circulation, which determines the residence time and transport of aerosols, and their interaction with the water cycle. Understanding the mechanisms and dynamics of aerosol-clouds-precipitation, and eventually implementing realistic aerosol-cloud microphysics in climate models are clearly important pathways to improve the reliability of predictions by climate and Earth system models. Laboratory scientists are involved in analyses of the interrelationships among satellite-derived quantities such as cloud optical properties, effective cloud radii, aerosol optical thickness (MODIS, TOMS, Cloudsat, and CALIPSO) rainfall, water vapor, cloud liquid water (TRMM, Advanced Microwave Sounding Radiometer [AMSR]), in conjunction with large scale circulation, moisture convergence (European Centre for Medium-Range Weather Forecasts [ECMWF] and National Center for Environmental Prediction [NCEP] re-analyses) in different climatic regions of the world, including the semi-arid regions of southwest U.S., the Middle East, northern Africa, and central and western Asia. Observations will be coordinated with modeling studies, using global and regional climate models, as well as cloud resolving models, coupled to land surface and vegetation models, and ocean models. A major goal of this research is to develop a fully interactive climate-aerosol climate system model, including data assimilation, so that atmospheric water cycle dynamics can be studied in a unified modeling and observational framework. Currently, the use of multimodel framework (MMF), including the embedding of cloud resolving models in global general circulation models, is being pursued. This research also calls for the organization and coordination of field campaigns for aerosol and water cycle measurements in conjunction with GEWEX, Climate Variability and Predictability Programme (CLIVAR), and other WCRP international programs on aerosols and water cycle studies. For more information, contact William Lau (William.K.Lau@nasa.gov), Mian Chin (Mian.Chin@nasa.gov), Si-Chee Tsay (Si-Chee.Tsay-1@climate.gsfc.nasa.gov), or W.K. Tao (Wei-Kuo.Tao-1@nasa.gov).

Atmospheric Hydrologic Processes and Climate

One of the main thrusts in climate research in the Laboratory is to identify natural variability on seasonal, interannual, and interdecadal time scales, and to isolate the natural variability from the human-made global-change signal. Climate diagnostic studies use a combination of remote sensing data, historical climate data, model output, and assimilated data. Diagnostic studies are combined with modeling studies to unravel physical processes underpinning climate variability and predictability. The key areas of research include ENSO, monsoon variability, intraseasonal oscillation, air–sea interaction, and water vapor and cloud feedback processes. More recently, the possible impact of anthropogenic aerosol on regional and global atmospheric water cycles is also included. A full array of standard and advanced analytical techniques, including wavelets transform, multivariate empirical orthogonal functions, singular value decomposition, canonical correlation analysis, nonlinear system analysis, and satellite orbit-related sampling calculations are used. Maximizing the use of satellite data for better interpretation, sampling, modeling, and eventually prediction of geophysical and hydroclimate systems is a top priority of research in the Laboratory.

Satellite-derived data sets for key hydroclimate variables such as rainfall, water vapor, clouds, surface wind, sea surface temperature, sea level heights, and land surface characteristics are obtained from a number of different projects: MODIS, AMSR, TRMM, the Quick Scatterometer Satellite (QuikSCAT) and Topography Experiment (TOPEX)/Poseidon, the Earth Radiation Budget Experiment (ERBE), Clouds and the Earth's Radiant Energy System (CERES), the International Satellite Cloud Climatology Project (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), TOMS, Special Sensor

Microwave Imager (SSM/I), MSU, and TOVS Pathfinder. Diagnostic and modeling studies of diurnal and seasonal cycles of various geophysical parameters will be conducted using satellite data to validate climate model output, and to improve physical parameterization in models. For more information, contact William Lau (William.K.Lau@nasa.gov), Tom Bell (Thomas.L.Bell@nasa.gov), or Yogesh Sud (Yogesh.C.Sud@nasa.gov).

Atmospheric Ozone Research

The Clean Air Act Amendment of 1977 assigned NASA the major responsibility for studying the ozone layer. Data from many ground-based, aircraft, and satellite missions are combined with meteorological data to understand the factors that influence the production and loss of atmospheric ozone. Analysis is conducted over different temporal and spatial scales, ranging from studies of transient filamentary structures that play a key role in mixing the chemical constituents of the atmosphere to investigations of global-scale features that evolve over decades.

The principal goal of these studies is to understand the complex coupling between natural phenomena, such as volcanic eruptions and atmospheric motions, with human-made pollutants, such as those generated by agricultural and industrial activities. These nonlinear couplings have been shown to be responsible for the development of the well-known Antarctic ozone hole.

An emerging area of research is to understand the transport of chemically active trace gases across the tropopause boundary, both into the stratosphere from the troposphere, and out of the stratosphere to the troposphere. It has been suggested that changes in atmospheric circulation caused by greenhouse warming may effect this transport and, thus, delay the anticipated recovery of the ozone layer in response to phase-out of CFCs. For more information, contact Paul A. Newman (Paul.A.Newman@nasa.gov).

First Measurements of Trace Gases (NO_2, SO_2, HCHO, O_3) Amounts Using a Brewer Double Monochromator

O_3, NO_2, HCHO, and SO_2 column amounts were measured by using a modified double Brewer spectrometer in direct-sun mode. A new “bootstrap” solar irradiance method of solar calibration has enabled the Brewer spectrometer to detect NO_2, HCHO, and SO_2 with a sensitivity of approximately 0.4 DU. The method for obtaining the column amounts uses a modified differential Optical Absorption Spectroscopy (DOAS) (spectral fitting) technique having the advantage that measured direct sun slant-column amounts can be accurately converted into vertical column amounts without needing to know the height distribution or making the unlikely assumption of horizontal homogeneity, especially in urban areas. The method described in this study can be applied to the worldwide Brewer network to obtain global distributions of pollution related trace gas amounts. Comparisons with Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) NO_2 data show good agreement. The results from this investigation have now been accepted for publication. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

First Simultaneous UV and Visible Wavelength Measurements of Aerosol Scattering and Absorption Properties

Very little is known about aerosol absorption in UV compared to the visible spectral region. Without such information, it is impossible to quantify the causes of the observed discrepancy between modeled and measured UV irradiances and photolysis rates. We have performed an aerosol UV absorption closure experiment using a UV-shadowband radiometer and a well-calibrated Cimel Sun–sky run side-by-side continuously for 17 months at the NASA GSFC site in Greenbelt, Maryland. The new combination of the two instruments has enabled the first determination of consistent aerosol scattering and absorption properties in both the visible and UV wavelength regions. Recently, we have extended these measurements by modifying the design of the shadowband instrument to include a new 440 nm channel that overlaps the Cimel sun photometer's shortest wavelength almucantar channel. The change should bridge the gap between the two data sets. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov).

Impact of Aerosols on Atmospheric Heating and Rainfall

The impact of smoke aerosols generated from biomass burning activities in Southeast Asia on the total reflected solar and emitted thermal radiation (direct and indirect effects) from clouds, was investigated using satellite data. Narrowband radiance measurements were combined with broadband irradiance measurements to quantify how smoke aerosols modulate the cloud radiative forcing. Results show that smoke in Southeast Asia is frequently present over large areas of cloud-covered regions during boreal spring. Depending on the loading of the smoke aerosols, the reflected solar (emitted thermal) radiation from clouds was reduced by as much as 100 Wm^{-2} or enhanced by as much 20 Wm^{-2} during spring conditions.

The effect of smoke aerosols produced by agricultural practice from the Indochina peninsula on the precipitation over southern China was carried out using long-term (~20 years) measurements of cloud fraction, precipitation, wind circulation, and aerosols from the combined satellite and model reanalysis data sets. We found that there are statistically significant indirect effects from smoke aerosols on clouds and precipitation in the South East and East Asia regions. Results show that the precipitation increased downstream from the peak aerosol concentrations and decreased in regions of high aerosol loading. This is caused by aerosols absorption of short wave radiation increasing air temperature and stabilizing the atmosphere in the area with high aerosol loading. These patterns are consistently observed during March through early May when more aerosols are produced from biomass burning. Mean southwesterly winds transport aerosols from biomass burning regions over dry Indochina to southern China where the mean climate is wetter in the premonsoon season spring of each year. Based on current measurements we find that the southern China monsoon now starts a couple of weeks earlier than the climatological mean onset date because of precipitation increased by aerosol–cloud interaction. We also found that the increase is not due to a northward shift of tropical cloud systems. These results help us understand the impact of large-scale biomass burning on the fresh water distribution in Southeast Asia and also helps in the prediction of the onset of the tropical monsoon system. For more information, contact Jay Herman (Jay.R.Herman@nasa.gov) or Christina Hsu (Nai.C.Hsu@nasa.gov).

Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the AMSR on EOS Aqua (AMSR-E).

The retrieval techniques include the following:

- A physical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface. This multifrequency technique also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations for improved estimations.
- An empirical relationship that relates cloud thickness, humidity, and other parameters to rain rates, using TOVS and Aqua–AIRS sounding retrievals.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, the climatological contribution of tropical cyclone rainfall, and the validation of global models. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Rain Measurement Validation for TRMM

The objective of the TRMM Ground Validation Program (GVP) is to provide reliable, instantaneous area- and time-averaged rainfall data from several representative tropical and subtropical sites worldwide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained at GV sites is available via the Goddard DAAC. With these products, the validity of TRMM measurements is being established with accuracies that meet mission requirements. For more information, contact Robert Adler (Robert.F.Adler@nasa.gov).

Unified Onboard Processing and Spectrometry

Increasingly, scientists agree that spectrometers are the wave of the future in passive Earth remote sensing. The difficulty, however, stems from the vast volume of data generated by an imaging spectrometer sampling in the spatial and spectral dimensions. The data volume from an advanced spectrometer could easily require 10 times the present EOS Data Information System (EOSDIS) capacity—something NASA simply cannot afford. A group of scientists and engineers at GSFC, led by Si-Chee Tsay, is funded by the Earth Science Technology Office (ESTO) Advanced Component Technologies (ACT), for a project to unify onboard processing techniques with compact, low-power, low-cost, Earth-viewing spectrometers being developed for eventual space missions. The philosophy is that spectrometry and its onboard processing algorithms must advance in lockstep, and eventually unite in an indistinguishable fashion. We envision a future in which archives of the spectrometer output will not be a monstrous data dump of spectra, but rather the information content of those spectra, undoubtedly a much smaller and more valuable data stream. In the meantime, we must quickly find ways to losslessly compress onboard spectra, using a combination of physics-based removal and proximal differencing, to the maximum extent possible. A system of hyperspectral imager Quantum Well Infrared Photodetectors (QWIP) has been integrated and flight-tested in a Navy research aircraft for building a testbed. We will perform the final phase of this project by flight testing our QWIP with an onboard simulator in the spring peak-season of biomass burning in a Southeast Asia field deployment. Currently, we are analyzing an effective flat-fielding algorithm, which will be applied to the Field Programmable Processor Array (FPPA), also known as Reconfigurable Data Path Processor (FPPA/RDPP) software simulator. In the meantime, we are implementing a cloud-detection algorithm in the FPPA/RDPP software simulator. The final goal is to demonstrate both flat-fielding and cloud-detection in "Real Time." We are also exploring lossy compressions for specific applications in Earth sciences. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

4.5 Modeling

Modeling is an important aspect of our research, and is the path to understanding the physics and chemistry of our environment. Models are intimately connected with the data measured by our instruments: models are used to interpret data, and the data is combined with models in data assimilation. Our modeling activities are highlighted below.

Aerosol Modeling

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. Aerosol is also a key component determining air quality. To understand the various processes that control aerosol properties and to understand the role of aerosol in atmospheric chemistry and climate, we have developed an atmospheric aerosol model, the Global Ozone Chemistry Aerosol Radiation Transport (GOCART) model. This model uses the meteorological fields produced by Goddard's Global Modeling and Assimilation Office (GMAO, Code 610.1), and includes major types of aerosol: sulfate, dust, black carbon, organic carbon, and sea salt. Among these, sulfate, and black- and organic carbon originate mainly from human activities—such as fossil fuel combustion and biomass burning—while dust and sea salt are mainly generated by natural processes, for example, uplifting dust from deserts by strong winds.

In 2005, the GOCART model was used as a major tool in the U.S. Climate Change Science Program (CCSP) report on aerosol direct radiative forcing assessment, which has contributed to the most recent report by the Intergovernmental Panel on Climate Change (IPCC). We have also used the model to study intercontinental transport, global air quality, aerosol climate forcing, and aerosol–chemistry–climate interactions. The output of the model is used by many groups worldwide. For more information, contact Mian Chin (Mian.Chin@nasa.gov), or go to the Web site http://code916.gsfc.nasa.gov/People/Chin/aot.html.

Chemistry-Climate Modeling

This project brings together the atmospheric chemistry and transport modeling of the Atmospheric Chemistry and Dynamics Branch and the General Circulation Model (GCM) development of the GMAO. The initial goal is to understand the role of climate change in determining the future composition of the atmosphere. We have coupled our stratospheric chemistry and transport into the Goddard Earth Observing System (GEOS) general circulation model and will use this to study the past and future coupling of the stratospheric ozone layer to climate. Our emphasis is on the testing of model processes and model simulations using data from satellites and ground-based measurement platforms.

Co-PIs are Richard Stolarski (Atmospheric Chemistry and Dynamics Branch) and Steven Pawson (GMAO). For further information, contact Richard Stolarski (Richard.S.Stolarski@nasa.gov), Steven Pawson (Steven.Pawson-1@nasa.gov), or Anne Douglass (Anne.R.Douglass@nasa.gov).

Cloud and Mesoscale Modeling

Three different coupled modeling systems were developed and improved over the last year. These models are used in a wide range of studies, including investigations of the dynamic and thermodynamic processes associated with cyclones, hurricanes, winter storms, cold rainbands, tropical and mid-latitude deep convective systems, surface (i.e., ocean and land, and vegetation and soil) effects on atmospheric convection, cloud–chemistry interactions, cloud–aerosol interactions, and stratospheric–tropospheric interaction. Other important applications include long-term integrations of the models that allow for the study of air–sea, cloud–aerosol, cloud–chemistry (transport), and cloud–radiation interactions and their role in cloud–climate feedback mechanisms. Such simulations provide an integrated system-wide assessment of important factors such as surface energy, precipitation efficiency, radiative exchange processes, and diabatic heating and water budgets associated with tropical, subtropical, and mid-latitude weather systems.

In the first modeling system, the NASA Goddard finite volume GCM (fvGCM) is coupled to the Goddard Cumulus Ensemble (GCE) model (a cloud-resolving model). The fvGCM allows for global coverage, and the GCE model allows for explicit simulation of cloud processes and their interactions with radiation and surface processes. This modeling system has been applied and its performance tested for two different climate scenarios, El Niño (1998) and La Niña (1999). The new coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems, intraseasonal oscillations, and diurnal variation of precipitation over land, which are very difficult to forecast using even state-of-the-art GCMs.

The second modeling system couples various NASA Goddard physical packages (i.e., microphysics, radiation, and a land surface model) into the next generation weather forecast model known as the Weather Research and Forecasting (WRF) model. This coupled modeling system allows for better forecasts (or simulations) of convective systems in Oklahoma and typhoons in the west Pacific.

The third modeling system is the improved GCE model system, which has been developed and improved at Goddard over the last two decades. The GCE model has recently been improved in its abilities to simulate the impact of atmospheric aerosol concentration on precipitation processes and the impact of land and ocean surfaces on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and precipitation radar model to simulate satellite-observed brightness temperatures at different frequencies. This new coupled model system allows us to better understand cloud processes in the tropics, as well as to improve precipitation retrievals from NASA satellites. The scientific output of the modeling activities was again exceptional in 2005 with 10 new papers published or in press and many more submitted. For more information, contact Wei-Kuo Tao (WeiKuo.Tao.1@gsfc.nasa.gov).

Global Modeling Initiative (GMI)

The GMI was initiated under the auspices of the Atmospheric Effects of Aviation Program in 1995. The goal of GMI is to develop and maintain a state-of-the-art modular 3-D chemical transport model (CTM), which can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including, but not limited to, the effect of aircraft. The GMI model also serves as a testbed for model improvements. The goals of the GMI effort follow:

- reduce uncertainties in model results and predictions by understanding the processes that contribute most to the variability of model results, and by evaluating model results against existing observations of atmospheric composition;
- understand the coupling between atmospheric composition and climate through coordination with climate models; and
- contribute to the assessment of the anthropogenic perturbations to the Earth system.

The GMI CTM has options for several chemical mechanisms for studying different problems. There are separate tropospheric, stratospheric, and aerosol chemical mechanisms, and recently we have added a combined tropospheric-stratospheric mechanism for investigations of the climatically sensitive upper troposphere/lower stratosphere. We have also added a microphysical aerosol mechanism for the study of aerosol size distributions and their role as cloud condensation nuclei. The chemical mechanisms have been recoded for compliance with the Earth Science Modeling Framework (ESMF). The sensitivity of the aerosol model results to meteorological input was evaluated by GMI team members at the University of Michigan. The GMI tropospheric model participated in an IPCC photochemical intercomparison that investigated model sensitivities to simulation of tropospheric ozone. An important aspect of all GMI studies is the evaluation of the credibility of model results using ground-based, aircraft, and remotely sensed measurements. Comparison to stratospheric observations and to tropospheric observations have been documented for model evaluation. For more information, contact Jose Rodriguez (jrodriguez@code916.gsfc.nasa.gov).

Physical Parameterization in Atmospheric GCM

The development of submodels of physical processes (physical parameterizations) is an integral part of preparing our climate models for addressing the remaining outstanding climate change questions. At this time, the scientific community is deeply divided about the feedback influence of clouds and cloud microphysics in a climate change scenario. Laboratory scientists are actively involved in developing and improving physical parameterizations of the moist processes effecting precipitation microphysics, cloud-radiation, and cloud-aerosol interaction, and in validation against *in situ* data and satellite data. The accuracy of such process interactions is extremely important for eliminating climate-model biases, and simulating realistic climate change, both of which are vital to a better understanding of the global water and energy cycles.

For atmospheric radiation, we are developing efficient, accurate, and modular longwave and shortwave radiation codes with parameterized direct effects of man-made and natural aerosols. The radiation codes allow efficient computation of climate sensitivities to water vapor, cloud microphysics, and optical properties of clouds and aerosols to simulate the direct effects of aerosols. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

With regard to the cloud physics, almost all of the state-of-the-art models of our times develop large simulation biases that are sometimes larger than the outstanding climate change issues to be assessed by these models; it is primarily due to the biased heating and moistening fields simulated by the model's cloud physics and microphysics. We are evaluating and eliminating such simulation biases using the Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme (McRAS), an in-house prognostic cloud-scale dynamics and cloud water substance scheme that includes representation of source and sink terms of cloud-scale condensation, microphysics of precipitation and evaporation, as well as horizontal and vertical advection of cloud water substance. Our cloud scheme incorporates attributes from physically based cloud life cycles, effects of convective updrafts and downdrafts, cloud microphysics within convective towers and anvils, cloud-radiation interactions, and cloud inhomogeneity corrections for radiative transfers based on algorithms developed by the laboratory scientists. The boundary-layer clouds are based on the physics of boundary-layer convection, which parallels the formulations of moist convection. Recently, we included a version of Nenes and Seinfield aerosol-cloud interaction scheme for water clouds while a parallel scheme for ice and mixed-phase clouds is an active area of research. These will be evaluated against ARM-2004 data on cloud particle number densities of water and ice clouds.

We have been evaluating coupled radiation and the prognostic cloud-water schemes with *in situ* observations from the ARM Cloud and Radiation Test Bed (ARM CART) and Tropical Ocean Global Atmosphere–Coupled Ocean Atmosphere Response Experiment (TOGA COARE) Integrated Program Offices (IOPs), as well as satellite data. Recently, GCM-simulated diurnal cycle of rainfall, that shows significantly different characteristics in different regions of the world, has become an active area of research; TRMM satellite rainfall retrievals also provide the essential validation statistics.

We have been using the Land Information System (LIS) for comparing four different sets of algorithms used to represent the hydrologic, snow-cover, and evapotranspiration processes for different biomes in each model. Moreover, the soil moisture prediction of our own model, called HYdrology and Simple Biosphere (HY-SiB) is extended down to the groundwater table. Two-year long integration with Global Soil Wetness Project (GSWP) forcing data from analysis of observations from 1987 and 1988 revealed several salient characteristics of each land model that would significantly impact climate change studies. All these improvements have been found to better represent the hydrologic cycle in climate simulation studies. Currently, we are performing objective intercomparisons of different parameterization concepts (applied to models and satellite data retrievals) within the GSFC laboratories. After the formation of the Global Modeling and Assimilation Office (GMAO), however, the project is currently with the Hydrospheric and Biospheric Sciences Laboratory and the GMAO. The National Center for Atmospheric Research (NCAR), (GFDL), and Goddard Institute for Space Studies (GISS) scientists are our active collaborators. For more information, contact Yogesh Sud (Yogesh.C.Sud@nasa.gov).

Trace Gas Modeling

The Atmospheric Chemistry and Dynamics Branch has developed two- and three-dimensional (2-D and 3-D, respectively) models to understand the behavior of ozone and other atmospheric constituents. We use the 2-D models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, or solar proton events, and human effects; such as changes in chlorofluorocarbons (CFCs), nitrogen oxides, and hydrocarbons. Three-dimensional stratospheric chemistry and transport models simulate the evolution of ozone and trace gases that effect ozone. The constituent transport is calculated using meteorological fields (winds and temperatures) generated by the GMAO or using meteorological fields that are output from a GCM. These calculations are appropriate to simulate variations in ozone and other constituents for time scales ranging from several days or weeks to seasonal, annual, and multi-annual. The model simulations are compared with observations, with the goal of illuminating the complex chemical and dynamical processes that control the ozone layer, thereby improving our predictive capability.

The modeling effort has evolved in the following directions:

(1) Lagrangian models are used to calculate the chemical evolution of an air parcel along a trajectory. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations.

(2) Two-dimensional noninteractive models have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used in both data analysis and multi-decadal chemical assessment studies.

(3) Two-dimensional interactive models include interactions among photochemical, radiative, and dynamical processes, and are used to study the dynamical and radiative impact of major chemical changes.

(4) Three-dimensional CTMs have a complete representation of photochemical processes and use input meteorological fields from either the data assimilation system or from a general circulation model for transport.

The constituent fields calculated using winds from a new GCM developed jointly by the GMAO and NCAR exhibit many observed features. We have coupled this GCM with the stratospheric photochemistry from the CTM to produce a fully interactive 3-D model that is appropriate for assessment calculations. We are also using output from this GCM in the current CTM for multi-decadal simulations. The CTM is being improved by implementation of a chemical mechanism suitable for both the upper troposphere and lower stratosphere. This capability is needed for interpretation of data from EOS Aura, which was launched in July 2004.

The Branch uses trace gas data from sensors on the Upper Atmosphere Research Satellite (UARS), on other satellites, from ground-based platforms, from balloons, and from various NASA-sponsored aircraft campaigns to test model processes. The integrated effects of processes such as stratosphere-troposphere exchange, not resolved in 2-D or 3-D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass@nasa.gov).

4.6 Support for NOAA Operational Satellites

In the preceding pages, we examined the Laboratory for Atmosphere's Research and Development work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA's operational remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists ensure scientific integrity throughout mission definition, design, development, operations, and data analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments fly on POES. Postdoctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

The Laboratory is supporting the formulation phase for the next generation GOES mission, known as GOES-R, which will supply a hundredfold increase in real-time data. Laboratory scientists are involved in specifying the requirements for the GOES-R advanced imager, high-resolution sounding suite, solar imaging suite, and *in situ* sensors. They participate in writing each Request for Proposal (RFP), and serve on each Source Evaluation Board (SEB) for the engineering formulation of these instruments. For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

GOES

GSFC project engineering and scientific personnel support NOAA for GOES. GOES supplies images and soundings for monitoring atmospheric processes, such as moisture, winds, clouds, and surface conditions, in real time. GOES observations are used by climate analysts to study the diurnal variability of clouds and rainfall, and to track the movement of water vapor in the upper troposphere. The GOES satellites also carry an infrared multichannel radiometer, which NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States to improve numerical forecasts of local weather. The GOES project scientist at Goddard provides free public access to real-time weather images via the World Wide Web (http://goes.gsfc.nasa.gov/). For more information, contact Dennis Chesters (Dennis.Chesters@nasa.gov).

NPOESS

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the SEB as technical advisors. Laboratory personnel were involved in evaluating proposals for the Ozone Mapper and Profiler System (OMPS) and the Crosstrack Infrared Sounder (CrIS), which will accompany the Advanced Technology Microwave Sounder (ATMS), and Advanced Microwave Sounding Unit (AMSU)-like crosstrack microwave sounder. Collaboration with the IPO continues through the Sounder Operational Algorithm Team (SOAT) and the Ozone Operational Algorithm Team (OOAT) that will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. We have conducted numerous trade studies involving CrIS and ATMS, the advanced infrared and microwave sounders, which will fly on NPP and NPOESS. Simulation studies were conducted to assess the ability of AIRS to determine atmospheric CO_2, CO, and CH_4. These studies indicate that total CO_2 can be obtained to 2 ppm (0.5%) from AIRS under clear conditions, total CH_4 to 1%, and total CO to 15%. This shows that AIRS should be able to produce useful information about atmospheric carbon. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

CrIS for NPP

CrIS is a high-spectral resolution interferometer infrared sounder with capabilities similar to those of AIRS. AIRS was launched with AMSU-A and the Humidity Sounder for Brazil (HSB) on the EOS Aqua platform on May 4, 2002. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. Current results with AIRS/AMSU/HSB data demonstrate that the temperature sounding goals for AIRS, i.e., root mean squared (RMS) accuracy of 1K in 1 km layers of the troposphere under partial cloud cover, are being met over the ocean. The AIRS soundings will be used in a pseudo-operational mode by NOAA/NESDIS and the NOAA/National Center for Environmental Prediction (NCEP). Simulation studies were conducted for the IPO to compare the performance of AIRS/AMSU/HSB with that expected of CrIS, as a function of instrument noise, together with AMSU/HSB. The simulations will help in assessing the noise requirements for CrIS to meet the NASA sounding requirements for the NPP bridge mission in 2006. Trade studies have also been done for ATMS, which will accompany CrIS on the NPP mission and replace AMSU/HSB. For more information, contact Joel Susskind (Joel.Susskind-1@nasa.gov).

Ozone Mapper Profiler Suite (OMPS)

OMPS will become the next U.S. operational ozone sounder to fly on NPOESS. The instrument suite has heritage from TOMS and SBUV for total ozone mapping and ozone profiling. The need for high performance profiles providing better vertical resolution in the lower stratosphere resulted in the addition of a limb scattering profiler to the suite. The limb scattering profiler instrument has heritage from the two Shuttle Ozone Limb Sounding Experiment (SOLSE)/Limb Ozone Retrieval Experiment (LORE) shuttle demonstration flights in 1997 (STS-87) and 2003 (STS-107). These missions were developed by our Laboratory with partial support by the IPO. Data from these experimental flights are being used by Laboratory staff personnel to characterize the OMPS instrument and algorithm.

Laboratory scientists continue to support the IPO through the OOAT and the NPP mission science team. Laboratory scientists are conducting algorithm research, advising on pre- and postlaunch calibration procedures, and providing recommendations for validation. They participate in reviews for the OMPS instrument contractor and the NPOESS system integrator. The Laboratory staff members are also assessing OMPS data for climate research. An algorithm has been developed to analyze the SAGE III data when SAGE III operates in a limb scattering mode, which will simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE-1 and SOLSE-2 missions. The advanced ultraviolet and visible radiative transfer models developed in the Laboratory over the last two decades enable this research. The two decades of experience in TOMS and SBUV calibration and validation will also be applied to OMPS. For more information, contact Richard McPeters (Richard.D.McPeters@nasa.gov).

Holographic Scanning Lidar Telescope Technology

Some lidar remote sensing applications require scanning a large aperture telescope over widely separated fields of view in rapid succession. Conical scanning telescopes that use a Holographic Optical Element (HOE) for their primary optic are being developed to reduce the size, weight, angular momentum, and costs associated with this type of scanning using conventional optical telescopes. Building on our prior successes in developing ground-based and airborne lidar systems using large rotating HOEs in the visible and 1-micron wavelength regions, we are now pushing this technology into the ultraviolet and 2-micron wavelength regions.

The first two lidars using HOE technology are the Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing (PHASERS) and HARLIE. PHASERS is a ground-based lidar using a 532 nm laser, and is now operated by Dr. David Guerra of the Physics Dept. at Saint Anselm College in Manchester, NH. HARLIE is a 1-micron wavelength backscatter lidar operated by GSFC. It is currently being modified for use at a wavelength of 355 nm and interfaced to a Doppler receiver for the first ground-based demonstration of atmospheric Doppler wind measurements using HOE technology. PHASERS and HARLIE have proven the utility of using HOEs as lidar receivers and demonstrated a factor of 3 reduction in the weight of the telescope/scanner assembly compared to conventional technology.

As part of their Instrument Incubator Program (IIP), ESTO is funding the development of a high-altitude airborne Doppler wind lidar that will use a 40 cm diameter rotating HOE telescope operating with a

355 nm laser transmitter called the Tropospheric Wind Lidar Instrument Technology Experiment (TWiLiTE), described previously in this report.

ESTO also began funding for the development of a Shared Aperture Diffractive Optical Element (ShADOE) telescope, under their Advanced Component Technology program. The ShADOE telescope will eliminate most or all mechanical moving components by sequentially "addressing" several holograms multiplexed into a single optic in order to scan over the multiple fields of view. This last development should reduce the weight of large aperture scanning receivers by another factor of three. The objectives of the ShADOE project follow:

- Enable atmospheric Doppler (e.g,, wind profiling) and surface mapping lidar applications from space;
- Develop diffraction-limited holographic, or diffractive optical, elements for use with 2054 nm wavelength lasers and near-diffraction limited ShADOEs for use at 355 nm;
- Demonstrate an angle-multiplexed, multi-wavelength ShADOE telescope suitable for use with single and dual-wavelength lidars; and
- Advance the ShADOE TRL from 2 to 4.

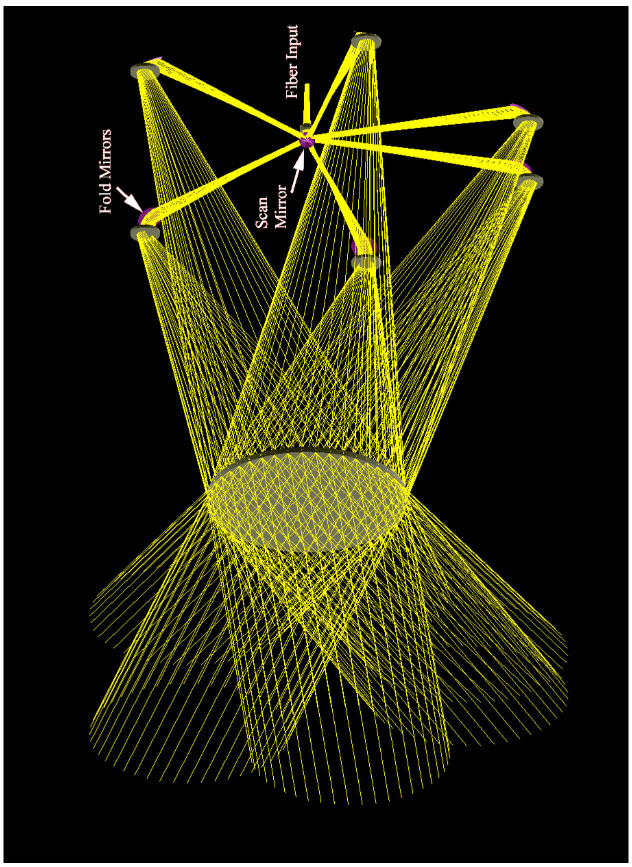


Figure 4.5. Illustration of how a ShADOE is used to multiplex six narrow fields of view into a single receiver system. Mechanical structures have been omitted for clarity; only the optical components and the ray paths are shown. The ShADOE is the large circular optic near the bottom, focusing light from each field of view to secondary optics located in a circle above. These direct the light to a centrally located small rotating scanner that feeds each beam in sequence into a common fiber optic.

Starting from a Director's Discretionary Fund (DDF) program in the early 1990s, this program is leveraged by prior and current investments by the NASA Small Business Innovation Research Program (SBIR) program, the Cross-Cutting Technology Program, and the GSFC Independent Research and Development (IRAD) and Core Competency programs. The IPO also supports the development of this technology as a risk reduction for lidar applications on NPOESS, including direct detection wind lidar systems. For more information on this technology, visit the Web site at http://harlie.gsfc.nasa.gov/, or contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

Tropospheric Wind Profile Measurements

Measurements of tropospheric wind profiles from ground, air, and spaceborne platforms are important for understanding atmospheric dynamics on a variety of time scales. Numerous studies have shown that direct measurement of global winds will greatly improve numerical weather prediction. Because of this importance, the operational weather forecasting communities have identified global tropospheric winds as the number one unmet measurement requirement in the Integrated Operational Requirements Document (IORD-1) for NPOESS, the next generation polar orbiting weather satellite. The Laboratory is using these requirements to develop new Direct Detection Doppler Lidar technologies and systems to measure tropospheric wind profiles, first from the ground and on high altitude aircraft, and then from satellites. Ground-based (see GLOW) and airborne (see TWiLiTE) Doppler lidar systems provide critical validation of new technologies proposed for eventual spaceborne operation. ESTO and the NPOESS IPO are supporting the effort. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

Tropospheric Wind Lidar Technology Experiment (TWiLiTE)

Global measurement of tropospheric winds is a key measurement for understanding atmospheric dynamics and improving numerical weather prediction. Global wind profiles remain a high priority for the operational weather community and also for a variety of research applications including studies of the global hydrologic cycle and transport studies of aerosols and trace species. In addition to space-based winds, a high altitude airborne system flown on UAV or other advanced platforms would be of great interest for studying mesoscale dynamics and hurricanes. The TWiLiTE project was selected in 2005 by ESTO as part of the IIP. TWiLiTE will leverage significant research and development investments in key technologies made in the past several years. The primary focus will be on integrating these subsystems into a complete molecular direct detection Doppler wind lidar system designed for autonomous operation on a high-altitude aircraft, such as the NASA WB-57, so that the nadir-viewing lidar will be able to profile winds through the full troposphere. TWiLiTE is a collaboration involving scientists and technologists from NASA Goddard, the NOAA Earth System Research Laboratory (ESRL), Utah State University Space Dynamics Lab, and industry partners Michigan Aerospace Corporation and Sigma Space Corporation. NASA Goddard and its partners have been at the forefront in the development of key lidar technologies (lasers, telescopes, scanning systems, detectors, and receivers) required to enable spaceborne global wind lidar measurement. The TWiLiTE integrated airborne Doppler lidar instrument will be the first demonstration of a airborne scanning direct detection Doppler lidar and will serve as a critical milestone on the path to a future spaceborne tropospheric wind system. For more information, contact Bruce Gentry (Bruce.M.Gentry@nasa.gov).

4.7 Project Scientists

Spaceflight missions at NASA depend on cooperation between two upper-level managers—the project scientist and the project manager—who are the principal leaders of the project. The project scientist provides continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Table 4.2 lists the project- and deputy project scientists for current missions; Table 4.3 lists the validation and mission scientists for various campaigns.

Table 4.2: Laboratory for Atmospheres project- and deputy project scientists.

Project Scientists		**Mission and Deputy Project Scientists**	
Name	Project	Name	Project
Robert Adler	TRMM	Anne Douglass	EOS Aura, UARS
Pawan K. Bhartia	TOMS	Ernest Hilsenrath[3]	EOS Aura
Robert Cahalan	EOS SORCE	Gerald Heymsfield	TCSP
Dennis Chesters	GOES	Hans Mayr	AIM
James Gleason	NPP	Matt McGill[4]	CALIPSO
Jay Herman	DSCOVR[2]	Matt McGill[4]	CloudSat
Charles Jackman	UARS	Steve Platnick	EOS Aqua
Eric Smith[1]	GPM	Marshall Shepherd[5]	GPM
Joel Susskind	POES	Si-Chee Tsay	EOS Terra
		Warren Wiscombe	ARM, Chief Scientist

1. Arthur Hou replaced Eric Smith in mid-2005.
2. DeepSpace Climate Observatory Project (formerly (Triana).
3. Joanna Joiner replaced Ernest Hilsenrath who retired in late 2005.
4. Matt McGill completed his responsibilities in November 2005.
5. Marshall Shepherd left NASA in late 2005.

Table 4.3: Laboratory for Atmospheres campaigns and mission scientists.

EOS Validation Scientist		**Field/Aircraft Campaigns**	
Name	Mission	Name	Campaign
David Starr	EOS	Paul Newman	AVE
		Si-Chee Tsay	UAE[2]
		Si-Chee Tsay	BASE-ASIA
		Judd Welton	MPLNET

4.8 Interactions with Other Scientific Groups

Interactions with the Academic Community

The Laboratory relies on collaboration with university scientists to achieve its goals. Such relationships make optimum use of government facilities and capabilities and those of academic institutions. These relationships also promote the education of new generations of scientists and engineers. Educational programs include summer programs for faculty and students, fellowships for graduate research, and associateships for postdoctoral studies. A number of Laboratory members teach courses at nearby universities and give lectures and seminars at U.S. and foreign universities. (See Section 6 for more details on the education and outreach activities of our Laboratory.) The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community.

NASA and non-NASA scientists work together on NASA missions, experiments, and instrument and system development. Similarly, several Laboratory scientists work on programs residing at universities or other Federal agencies.

The Laboratory routinely makes its facilities, large data sets, and software available to the outside community. The list of refereed publications, presented in Appendix 2, reflects our many scientific interactions with the outside community; over 85% of the publications involve coauthors from institutions outside the Laboratory.

A prime example of the collaboration between the academic community and the Laboratory is given in this list of collaborative relationships via Memoranda of Understanding or cooperative agreements:

- Cooperative Institute of Meteorological Satellite Studies (CIMSS) with the University of Wisconsin, Madison;
- ESSIC, with the University of Maryland, College Park;
- GEST Center, with the University of Maryland, Baltimore County (and involving Howard University);
- JCET, with the University of Maryland, Baltimore County; and
- Joint Center for Observation System Science (JCOSS) with the Scripps Institution of Oceanography, University of California, San Diego.
- Cooperative agreement with Colorado State University, Fort Collins, CO.

These collaborative relationships have been organized to increase scientific interactions between the Laboratory for Atmospheres at GSFC, and the faculty and students at the participating universities.

In addition, university and other outside scientists visit the Laboratory for periods ranging from one day, to as long as two years. Some of these appointments are supported by Resident Research Associateships offered by the National Research Council (NRC) of the National Academy of Sciences; others, by the Visiting Scientists and Visiting Fellows Programs currently managed by the GEST Center. Visiting Scientists are appointed for up to two years and perform research in pre-established areas. Visiting Fellows are appointed for up to one year and are free to carry out research projects of their own design.

Interactions with Other NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with other NASA Centers and Federal laboratories.

Our ties with the other NASA Centers broaden our knowledge base. They allow us to complement each other's strengths, thus increasing our competitiveness while minimizing duplication of effort. They also increase our ability to reach the Agency's scientific objectives.

Our interactions with other Federal laboratories enhance the value of research funded by NASA. These interactions are particularly strong in ozone and radiation research, data assimilation studies, water vapor and aerosol measurements, ground-truth activities for satellite missions, and operational satellites. An example of interagency interaction is the NASA/NOAA/National Science Foundation (NSF) Joint Center for Satellite Data Assimilation (JCSDA), which is building on prior collaborations between NASA and NCEP to exploit the assimilation of satellite data for both operational and research purposes.

Interactions with Foreign Agencies

The Laboratory has cooperated in several ongoing programs with non-U.S. space agencies. These programs involve many of the Laboratory scientists.

Major efforts include the Tropical Rainfall Measuring Mission (TRMM), with the Japanese National Space Development Agency (NASDA); the TOMS Program, with NASDA and the Russian Scientific Research Institute of Electromechanics (NIIEM); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, Africa, and Asia. Another example of international collaboration was in the SOLVE II (SAGE III Ozone Loss and Validation Experiment) campaign, which was conducted in close collaboration with the Validation of International Satellites and study of Ozone Loss (VINTERSOL) campaign sponsored by the European Commission. More than 350 scientists from the United States, the European Union, Canada, Iceland, Japan, Norway, Poland, Russia, and Switzerland participated in this joint effort, which took place in January 2003. In 2004, another international collaboration started with the upload of instruments for the Polar Aura Validation Experiment (PAVE). PAVE is an Aura satellite validation involving instruments on the DC-8. Many of the experimenters from SOLVE II are involved in this campaign, which took place in late January and early February of 2005.

Laboratory scientists interact with about 20 foreign agencies, about an equal number of foreign universities, and several foreign companies. The collaborations vary from extended visits for joint missions, to brief visits for giving seminars, or working on joint science papers.

4.9 Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports Government–Industry partnerships, SBIR projects, and technology transfer activities. Successful technology transfer has occurred on a number of programs in the past and new opportunities will become available in the future. Past examples include the MPL, holographic optical scanner technology, and Circle to Point Conversion Detector. New research proposals involving technology development will have strong commercial partnerships wherever possible.

5. HIGHLIGHTS OF LABORATORY ACTIVITIES IN 2005

This section highlights the Laboratory's accomplishments for 2005. The summaries are written by the Branch Heads, and give examples of the research carried out by Branch scientists and engineers. Additional activities are described in Section 5.4, Laboratory Highlights. These highlights are supplemented by NASA press releases in Appendix 1, by a complete listing of refereed papers that appeared in print in 2005 in Appendix 2, and by abstracts of highlighted journal articles in Appendix 3. For more details on Branch science activities, the Branch Web sites can be accessed from the Laboratory for Atmospheres home page at http://atmospheres.gsfc.nasa.gov/.

5.1 Mesoscale Atmospheric Processes Branch, Code 613.1

The Mesoscale Atmospheric Processes Branch seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. Research is conducted on the physical and dynamical properties and on the structure and evolution of meteorological phenomena, ranging from synoptic scale down to microscales, with a strong focus on the initiation, development, and effects of cloud systems. A major emphasis is placed on understanding energy exchange and conversion mechanisms, especially cloud microphysical development and latent heat release associated with atmospheric motions. The research is inherently focused on defining the atmospheric component of the global hydrologic cycle, especially precipitation, and its interaction with other components of the Earth system. Branch members participate in satellite missions and develop advanced remote sensing technology with strengths in the active remote sensing of aerosols, water vapor, winds, and convective and cirrus clouds. There are also strong research activities in cloud system modeling, and in the analysis, application, and visualization of a great variety of data.

Branch scientists develop retrieval techniques to estimate precipitation using satellite observations from TRMM and other satellites such as GOES and the AMSR-E sensor on EOS Aqua. The major accomplishments this year were in the areas of TRMM algorithm improvement and achieving continued operation of the TRMM satellite. In particular, there were significant publications on the latent heating data product. The accuracy of the TRMM algorithms continues to improve. The TRMM Ground Validation team supports this achievement through processing and analysis of data from rain gauge networks and ground-based radars. Six years of high quality data are now available through the Goddard DAAC. TRMM and other precipitation data are used within the Branch for a wide spectrum of studies on precipitating cloud systems and the global water cycle. Increasingly, these activities integrate global or regional data sets with modeling. Research is conducted on the assimilation of TRMM observations into models to explore the potential benefits to weather forecasting, such as for hurricanes, and to improve understanding of precipitating cloud systems. Branch scientists are also an integral part of the developing Global Precipitation Measurement (GPM) mission. Significant progress has been achieved in formulating this mission including incorporation of high-frequency channels for the GPM Microwave Imager (GMI) to improve light rain and snowfall measurement capabilities. Various NASA and international workshops and meetings were held to advance the formulation of the mission and validation program.

Development of lidar technology and application of lidar data for atmospheric measurements are also key areas of research. Systems have been developed to characterize the vertical profile structure of cloud systems (CPL), atmospheric aerosols (MPLNET), water vapor (SRL and RASL), and winds (GLOW) at fine temporal and/or spatial resolution from ground-based or airborne platforms. In addition, CPL and the CRS, a millimeter-wavelength radar for profiling cloud systems, have been integrated on NASA's high altitude WB-57 research aircraft for use in sensing the microphysical properties of cirrus and other cloud types. These systems will participate in field campaigns to validate NASA's Aura satellite, and CloudSat and CALIPSO.

A major accomplishment in 2005 was the success of three IIP proposals. These were: TWiLiTE, an airborne direct detection Doppler lidar to measure wind profiles through the troposphere (0–17 km) using the laser signal backscattered from molecules; HIWRAP, a conical scanning Doppler radar to provide horizontal winds within precipitation and clouds, and ocean surface winds in addition to more traditional 3-D radar reflectivity and hydrometeor characteristics; and the Airborne Water, Aerosol, Cloud, and Carbon Dioxide Lidar—an Airborne Raman Lidar to simultaneously profile water vapor mixing ratio, aerosol backscattering, extinction and depolarization, and cirrus cloud properties, as well as cloud liquid water and carbon dioxide concentration. Development of these exciting new capabilities presents a major challenge.

Initial papers on results from GLAS were published in a special issue of GRL and elsewhere on topics ranging from applications to global circulation models, to ocean surface signals. Improvements in data processing algorithms continued. In addition, an improved technique for infrared (IR) stereo cloud retrievals including multiple layer analysis was demonstrated with data from the STS-85 shuttle mission of the Infrared Spectral Imaging Radiometer (ISIR) Uncooled Microbolometer Array Detector (UMAD) instrument. Final testing of the COVIR IIP instrument is ongoing.

The MPLNET project underwent a major expansion in 2005. There are currently 10 active sites in the network: 3 in the U.S., 3 in Asia, 2 in Antarctica, 1 in the Arctic, and 1 off the west coast of Africa. Data from several of the sites are publicly available on our Web site, and the remaining sites will soon be public after calibrations are completed. Older data sets from an additional 14 sites remain available. Planning is underway for future sites in 2006–2007, including additional sites in the U.S., Asia, and the west coast of Africa, and new sites in the Caribbean, South America, and the Middle East. MPLNET is preparing for validation of CALIPSO after launch (spring 2006) and will participate in the African Monsoon Multidisciplinary Analysis (AMMA) campaign later in 2006. MPLNET results were compared against competing techniques and were found to have one of the lowest bias errors of all the methods available. Profiles of aerosol extinction are a primary MPLNET data product and an important data product to validate CALIPSO. The paucity of aerosol profile data is a major source of uncertainty in assessing global and regional climate models.

The Raman Lidar group is engaged in a broad range of research involving development and use of technologies for studying atmospheric processes including 1) Aqua and AURA satellite measurement validation; 2) development of an airborne Raman Lidar with the ability to profile water vapor, aerosols, clouds and other quantities during both day and night; and 3) development of the capability to remotely quantify aerosol physical properties using multi-wavelength Raman lidar. Two University of Maryland Baltimore County (UMBC) Ph.D. graduate students and one Ph.D. graduate student from University of Maryland College Park (UMCP) are supported and two visiting scientists from Brazil are currently working with the group. There is also substantial interaction with Howard University (HU) graduate students at the HU Beltsville Research Campus.

The branch is active in the development and application of atmospheric modeling systems. Three major development efforts were achieved in the past year. The NASA fvGCM and GCE model, a cloud-resolving model, were coupled in a multiscale modeling approach. The use of the fvGCM allows global coverage, and the GCE model provides explicit simulation of cloud processes and their interactions with radiation and surface processes, in contrast with conventional parametric approaches. This modeling system has been applied and tested for two different climate regimes, El Niño (1998) and La Niña (1999). The new coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems and intraseasonal oscillations, which are very difficult to forecast using conventional GCMs. A second major effort involved coupling various NASA Goddard physical packages (microphysics, radiation, and land surface models) into a next generation weather forecast model (called weather and research forecast model, or WRF). The new coupled modeling system allows better forecasting (or simulation) of convective systems and tropical typhoons. Lastly, an improved GCE modeling system has been developed at Goddard over the last two decades. The GCE model has been recently improved to simulate the impact of atmospheric aerosol concentration on precipitation processes, and the impact of land and ocean surface on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and precipitation radar model to simulate the satellite observed brightness temperature at various frequencies.

This new coupled model system allows us to investigate tropical cloud processes and improves the precipitation data retrieved from NASA satellites.

Branch scientists conducted research in the areas of hurricane formation, structure, and precipitation processes with an emphasis on storms that occurred during special NASA field programs such as CAMEX-4 and the TCSP experiment. Numerical forecast models, such as Mesoscale Model 5 (MM5) and WRF, were applied to simulate observed storms at very high grid resolution. The results were compared to field program and satellite (e.g., TRMM) measurements. Analysis of the results led to improved understanding of precipitation organization, storm structure, and their relationship to intensity change. Numerical models and TRMM satellite data are also used to study the organization of precipitation in winter storms, the mechanisms responsible for that organization, as well as climatological aspects of winter precipitation at lower mid-latitudes (approximately 24–35°N).

The impact of urbanization on precipitation variability was also explored. The impact of future urbanization on regional climate was investigated using a combination of an urban growth model (UrbanSim), MM5, and land surface model NOAH[4]. Major finds indicate that Houston urban land use in the year 2025 will significantly impact regional cloud and precipitation variability. Results suggest that runoff and potential urban flooding impacts will be elevated because of urban-enhanced convective events. TRMM-based and ground-based rainfall products were used to identify urban rainfall anomalies around Tokyo, Phoenix, Indianapolis, and other urban centers.

5.2 Climate and Radiation Branch, Code 613.2

One of the most pressing issues we face is to understand the Earth's climate system and how it is effected by human activities now and in the future. This has been the driving force behind many of the activities in the Climate and Radiation Branch. We have made major scientific contributions in five key areas: hydrologic processes and climate, aerosol–climate interaction, clouds and radiation, model physics improvement, and technology development. Examples of these contributions may be found in the list of refereed papers in Appendix 2 and in the material on the Code 613.2 Branch Web site, http://climate.gsfc.nasa.gov.

Besides scientific achievements, we have made great strides in many areas of science leadership, as well as science enabling, education, and outreach. Thanks to the organizational efforts of Yoram Kaufman and Lorraine Remer, the AeroCenter seminar series continues to run well and is very well attended. The biweekly seminars overflow the meeting room and attract aerosol researchers from NOAA and the University of Maryland on a regular basis. Collaborative papers between AeroCenter members from different disciplines are now commonplace. Previous AeroCenter visitors submit papers based on the work done during their visits to Goddard. MODIS data have been used for quantitative assessment of the emission, transport, and fate of dust from Africa. The MODIS data shows, in agreement with chemical transport models, that 120 Tg of dust are deposited annually into the oceans. It also resolves an old paradox about the need of Saharan dust as the main fertilizer of the Amazon basin and the amount of dust that was calculated to arrive in the Amazon region. Evidence was found that heavy smoke in the Amazon significantly reduces formation of boundary layer cumulus clouds and can change the smoke forcing from net cooling to net warming for which a paper was published in *Science*. A strong collaboration has been established with the Environmental Protection Agency (EPA) and with NASA/Langley Research Center for the purpose of air quality monitoring and forecasting. As part of NASA's Applications effort (Code

---

[4] NOAH is a nested acronym defined as the **N**ational Centers for Environmental Prediction (NCEP), **O**regon State University (Dept of Atmospheric Sciences), **A**ir Force (both AFWA and AFRL—formerly AFGL, PL), **H**ydrologic Research Lab of the NWS (now Office of Hydrologic Development)

YO) the potential of using the MODIS aerosol products as a Decision Support Tool within the EPA's Air Quality Decision Support System has been demonstrated. The availability of MODIS cloud and aerosol products has opened many new pathways of research in climate modeling and data assimilation in the Laboratory. In recognition of his leadership in aerosol research, in 2004 Yoram Kaufman was elected a Fellow of the American Meteorological Society (AMS).

We continue to serve in key leadership positions on international programs, panels, and committees. Si-Chee Tsay leads a group of scientists from NASA and universities in initiating a new project—Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment (BASE-ASIA), to study the effects of smoke aerosol on tropospheric chemistry, water and carbon cycles, and their interactions in the Southeast Asia monsoon region, using multiplatform observations from satellites, aircraft, networks of ground-based instruments, and dedicated field experiments. Robert Cahalan serves as project scientist of SOlar Radiation and Climate Experiment (SORCE) launched January 25, 2003. SORCE is measuring both Total Solar Irradiance (TSI, formerly "solar constant") and Spectral Solar Irradiance (SSI) with unprecedented accuracy and spectral coverage (1–2000 nm for SSI, 1–100,000 nm for TSI) during a 5-year nominal mission lifetime. Cahalan is also chairing the Observations Working Group of the Climate Change Science Program Office, tasked to evaluate and coordinate multiagency contributions to the U.S. Government climate observing system. He also chairs the 3-Dimensional Radiative Transfer Working Group of the International Radiation Commission and directs the International Intercomparison of 3-Dimensional Radiation Codes. In recognition of his long-standing leadership in radiative transfer, during 2004, Warren J. Wiscombe of the Climate and Radiation Branch was elected President of the Atmospheric Sciences Section of the American Geophysical Union (AGU).

The Climate and Radiation Branch Web site (http://climate.gsfc.nasa.gov) has a front page that changes almost daily. It provides the latest news in climate research and automatically updates the calendars of users who subscribe. Its "Image of the Week" highlights research by Branch members. A search page provides easy access to archived news, images, publications, and other climate information and data. The Branch Web site also has an extensive glossary of Earth science acronyms and a list of links to related sites. The Earth Observatory Web site (http://earthobservatory.nasa.gov) also continues to provide the science community with direct communication gateways to the latest breaking news on NASA Earth Sciences. It provides the news media and other communications outlets with a "one-stop shopping" resource for publication-quality images and data visualizations from NASA Earth Science satellite missions such as Terra, Aqua, and many others. The Earth Observatory Web site now boasts over 27,000 subscribers, with roughly 1 million page views per month worldwide. The contents of the Web site are increasingly syndicated by NASA Headquarters and other public sites.

In 2005, several key new findings have arisen from branch research. MODIS aerosol products now enable forecasting *Air Quality*, based on a NASA-EPA partnership. MODIS *Global Annual Direct Aerosol Radiative Forcing* over clear sky oceans is estimated to be -5.3 ± 0.6 Wm^{-2}. For the NE Pacific, aerosols enhance radiative cooling by -7 Wm^{-2} for overcast conditions. *Evolution of aerosol* over land and water surfaces is being tracked using combined Terra-Aqua data. Smoke from African fires increases cloud coverage by ~ 0.1 while reducing cloud droplet size.

A new method to measure aerosol absorption from space has been developed. The method measures aerosol attenuation of sun glint over the ocean to derive aerosol absorption. The method will be best applied to future satellites that can measure the same spot over the ocean at an angle at glint and at an angle off glint. A method to simultaneously analyze measurements from a two-wavelength lidar and a passive spectroradiometer, such as MODIS, has been introduced. The MODIS data are used to constrain the lidar inversion, thus decreasing the weight of assumptions in retrieving the aerosol profiles. The method was applied to Saharan dust and smoke from Africa in two field experiments.

The new MODIS "collection 5" level-2 *operational cloud algorithm* includes pixel-level uncertainties and multilayer cloud detection for thin upper-layer clouds. Alexander Marshak is an editor (together with A. Davis from Los Alamos) of the "Three-Dimensional Radiative Transfer for Cloudy Atmospheres" monograph being published by Springer-Verlag. He also has authored and coauthored three chapters in the book. Two additional chapters were authored by R. Cahalan and W. Wiscombe. The 3rd Intercomparison of 3D Radiation Codes (I3RC) workshop took place on a boat on the Baltic Sea, with branch members R. Cahalan and A. Marshak leading this international coordination of 3-dimensional radiative transfer activities.

Major Field Operations led by the branch include BASE-ASIA and the United Arab Emirates Unified Aerosol Experiment (UAE[2]), deployments of SMART-COMMIT. Warren Wiscombe became Chief Scientist of the DOE/ARM Program. An ARM "thermometer" was developed to measure for cloud liquid water. At the Williamsburg Aerosol Strategy Meeting, the CLAIM-3D concept was recommended to become a NASA HQ directed mission. New 3-D radiative transfer results have demonstrated CLAIM-3D's potential for retrieving cloud droplet vertical profiles. IUGG-2007 Joint Symposium on 3DRT (3-D Radiative Transfer), co-sponsored by IAMAS[5], IAHS[6], and ICCS[7], to be convened by R. Cahalan, with co-convener B. Mayer of DLR[8]. The THOR Lidar System has validated precise measurements of the thickness of 1 km thick clouds, to a precision of 50 m. THOR is now being modified for measurement of ice and snow thicknesses.

Six years of TRMM data show a *weekly cycle*: over the continental U.S. in summer, rain intensity and area increase midweek when pollution is at its maximum; with opposite behavior over nearby waters. This finding provides new potential for determining the influence of human activities on rainfall.

A new activity that is now being co-hosted by the Climate and Radiation Branch and the Goddard Solar Physics Branch is the Goddard Sun-Climate Center. The Sun-Climate Center, like the AeroCenter, is a crosscutting activity within Goddard's Sun–Earth Exploration Directorate. The Center sponsors research on solar system climate, and investigates new opportunities for advancing the understanding of the Sun's forcing of Earth's climate. Visiting scientists from Germany and Japan have recently joined this effort, and the Center receives advice from an international panel of experts. The Center will sponsor a seminar series, and will encourage new collaborations between scientists studying Earth, the Sun, and Earth's Moon. See http://sunclimate.gsfc.nasa.gov

5.3 Atmospheric Chemistry and Dynamics Branch, Code 613.3

The Atmospheric Chemistry and Dynamics Branch develops computer models and remote sensing instruments and techniques as aids in studies of aerosol, ozone, and other trace gases that affect chemistry, climate, and air quality on Earth. The Branch is an internationally acclaimed center of research in stratospheric chemistry. Using satellite, aircraft, balloon, and ground-based measurements, coupled with data analysis and modeling, Branch scientists have played a key role in improving our understanding of how human-made chemicals affect the stratospheric ozone layer.

Branch scientists have been active participants in satellite research projects. In the late 1960s, our scientists pioneered development of the backscattered ultraviolet (BUV) satellite remote sensing technique. Applying this technique to data taken from NASA and NOAA satellites, Branch scientists have produced a unique long-term record of the Earth's ozone shield. The data record now spans more than three decades, and provides scientists

[5] International Association of Meteorology and Atmospheric Sciences
[6] International Association of Hydrological Sciences
[7] International Conference on Conceptual Structures
[8] *Deutsches Zentrum für Luft und Raumfahrt* (German Aerospace Center)

worldwide with valuable information about the complex influences of Sun, climate, and weather on ozone and ultraviolet radiation reaching the ground. Branch scientists expect to maintain this venerable record using data from a series of BUV-like instruments that are planned for use on U.S. and international satellites in the next two decades. Branch scientists were also instrumental in developing the UARS project, which generated data used by researchers to produce a highly detailed view of the chemistry and dynamics of the stratosphere. Currently, Branch scientists are providing scientific leadership for the EOS Aura satellite, which was launched on July 15, 2004. Aura contains four advanced instruments to study the stratospheric ozone layer, chemistry and climate interactions, and global air quality. Branch scientists are also involved in the design of instruments, algorithms, and data systems for the new generation of ozone sensors on the operational weather satellites (NPP and NPOESS) and are developing state-of-the-art instruments to monitor air quality and tropospheric chemical species from spacecraft located at high vantage points (at distances ranging from 20,000–1,500,000 km from Earth). In addition, they operate a suite of advanced active and passive remote sensing instruments to study the chemical composition of the Earth's atmosphere from ground and aircraft. The branch has recently developed an advanced instrument and algorithm capability for ground-based validation of OMI satellite aerosol, NO_2, SO_2, and O_3 data.

The measurement activities of the Branch are highly coupled with modeling and data analysis activities. The Branch maintains state-of-the-art 2-D and 3-D chemistry models that use meteorological data, produced by the GMAO, to interpret global satellite and aircraft measurements of trace gases. Results of these studies are used to produce congressionally-mandated periodic international assessments of the state of the ozone layer, as well as to provide a strategic plan for guidance in developing the next generation of satellite and aircraft missions. A major new thrust of the Branch is to apply the unique synergy between Branch modeling and measurement groups, which proved very successful for the study of stratospheric chemistry, to study chemically and radiatively active tropospheric species, including aerosol, CO_2, O_3, CO, NO_x, and SO_2, which effect climate, air quality, and human health.

The following provides more detailed descriptions of some of the current Branch activities:

3-D Stratospheric Chemistry Model Studies

Branch scientists are analyzing a series of chemical transport model simulations of stratospheric ozone chemistry. These results are being compared with long-term data records from satellites and ground-based instruments. The goal is to use the model results to draw inferences about long-term ozone trends due to decrease in stratospheric chlorine and anticipated changes in the global climate.

The Branch is working collaboratively with the GMAO to couple chemistry to the dynamics in their general circulation models for chemistry–climate studies. The stratospheric chemistry used in the chemistry-transport studies has been coupled to the GEOS 4 GCM. The resulting chemistry-climate model has been integrated for 55 years simulating the period from 1950 through 2004. Time-slice simulations with repeating conditions for 1980, 2000, and 2020 have been run for 25 years each. These simulations are directed at understanding the role of ozone in climate change over the coming decades and the role of climate change in modifying the response of ozone to CFCs.

Global Modeling Initiative (GMI)

The goal of GMI is to develop and maintain a state-of-the-art modular 3-D CTM that can be used for assessing of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including the effects of aircraft. The GMI model also serves as a testbed for model improvements.

The GMI CTM has options for several chemical mechanisms for studying different problems. Recently, we have added a combined tropospheric-stratospheric mechanism for investigations of the climatically sensitive upper troposphere/lower stratosphere, and a microphysical aerosol mechanism for the study of aerosol size distributions and their role as cloud condensation nuclei. The chemical mechanisms have been recoded for compliance with the ESMF. The sensitivity of the aerosol model results to meteorological input was evaluated by GMI team members at the University of Michigan. The GMI tropospheric model participated in an IPCC photochemical intercomparison which investigated model sensitivities to simulation of tropospheric ozone. An important aspect of all GMI studies is the evaluation of the credibility of model results using ground-based, aircraft, and remotely sensed measurements. Several papers comparing GMI results with observations are currently in preparation.

OMI Data Analysis

The OMI, built by Dutch/Finnish collaboration, was launched on NASA's EOS Aura satellite in July 2005. The primary objective of OMI is to continue the long-term record, created by the Branch scientists, of total ozone, tropospheric ozone, UVB, aerosols (primarily smoke and desert dust), and volcanic SO_2 using data from NASA's TOMS instrument series. OMI is also designed to measure several other trace gases important for air quality studies, including NO_2, anthropogenic SO_2, and BrO, with improved spatial and temporal resolution compared to data from previous instruments (the Global Ozone Monitoring Experiment [GOME] and SCIAMACHY) on European satellites. Several Branch scientists are members of a NASA-funded U.S. science team, which is led by Dr. Pawan K. Bhartia, the Branch Head. In 2005, the Branch scientists developed and released several TOMS-like data products from OMI. Preliminary analysis shows that these data are of better quality and have significantly greater accuracy and precision than that from TOMS, particularly for SO_2. Several new products, not previously available from TOMS, have also been produced and are currently being validated. Several scientific papers describing this work will appear in the journals in 2006.

Global Aerosol Studies

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. To understand the various processes that control the aerosol properties and to understand the role of aerosol in atmospheric chemistry and climate, the Branch scientists have developed the GOCART model. In the past few years, the GOCART model has been used to study tropospheric aerosol and its effect on air quality and climate forcing. Major types of aerosol particles are simulated, including sulfate, dust, black carbon, organic carbon, and sea salt. Among these, sulfate, and black- and organic carbon mainly originate from human activities, such as fossil fuel combustion and biomass burning. Dust and sea salt are mainly generated by natural processes such as the uplift of dust from deserts by strong winds.

The modeling activities have been strongly connected to the satellite and aircraft observations. Our recent research involves studies of intercontinental transport of dust and pollutants using a combination of models and data. The data is from satellite observations (MODIS, MISR, and TOMS), ground-based network (AERONET), and *in situ* measurements (Aerosol Characterization Experiment–Asia [ACE-Asia], surface measurements from EPA and Interagency Monitoring of Protected Visual Environments [IMPROVE] networks). The aerosol absorption in the atmosphere is based on the GOCART model and AERONET data, and the aerosol radiative forcing is based on assimilated products of the model and MODIS data. In addition, the model results are used by many groups worldwide for studies of air pollution, radiation budget, tropospheric chemistry, hydrological cycles, and climate change. The model has participated in the recent international project of Global Aerosol Model Intercomparison (AEROCOM) and played a major role in the new Climate Change Science Program (CCSP) reports on aerosol direct climate forcing.

Measurement and Modeling of Atmospheric Carbon Dioxide

Recent Laboratory progress in carbon cycle science has come in the areas of atmospheric transport modeling and instrument construction and testing. The atmospheric chemistry and transport model, used for calculating global CO_2 transport, has incorporated a land biosphere emissions model and satellite data-constrained biomass burning emissions to produce CO_2 fields that are closely tied to actual meteorology and emission events. The modeling group is actively participating in an international model intercomparison exercise, TransCom-C, which is aimed at improving models' ability to utilize upcoming space-based CO_2 observations, such as the Orbiting Carbon Observatory. We are also collaborating with the GMAO in a new effort to develop a carbon cycle data assimilation system. We are in a collaborative effort with the Hydrospheric and Biospheric Sciences Laboratory to develop an airborne CO_2 laser sounder under the IIP. The modeling effort will help to optimize the sounder measurement characteristics through observing system simulation experiments. A partner instrument, the ground-based laser CO_2 profiler, is also being developed in the Laboratory for Atmospheres. The laser profiler has recently achieved CO_2 detection in reflection from clouds and has made range-resolved measurements of aerosols at both the online and offline wavelengths. This is the final step in making range-resolved measurements of CO_2 within the planetary boundary layer. The real-time CO_2 observations will be compared with modeled distributions to improve our knowledge of the coupling between carbon cycle processes and climate change.

Sun–Earth Connection Studies

Branch members were involved in several investigations into the influence of the Sun on the Earth's atmosphere. One study published in 2005 involved the effect of the very large solar storms in October–November 2003 on the middle atmosphere. The solar proton event of October 28–31, 2003 was the fourth largest of the past 40 years and caused huge NO_x (N, NO, NO_2) enhancements measured by the HALOE instrument and significant ozone depletions measured by the SBUV/2 instrument in the middle atmosphere. Another published study focused on the impact of all solar proton events in the years 2000–2003 on the middle atmosphere. This work showed polar total ozone depletions >1% lasting for several months past three of the event periods because of the large NO_x increases due to the intense flux of solar protons.

New Instrument Development

Two new instruments are nearing completion under the IIP, the Solar Viewing Interferometer Prototype (SVIP) and the GeoSpec (Geostationary Spectrograph). The SVIP is a 1.3 m prototype of an 8 m instrument that will make measurements between 1–4 μ to determine the amounts of CO_2, H_2O, O_3, N_2O, and CH_4 in the Earth's atmosphere from a position at L2. The SVIP is designed for testing in the laboratory, outside at Goddard, and on a mountaintop. The GeoSpec is a dual spectrograph operating in the UV/VIS and VIS/Near-Infrared (NIR) wavelength regions to measure trace gas concentrations of O_3, NO_2, and SO_2, coastal and ocean pollution events, tidal effects, and aerosol plumes. GeoSpec is intended to support future missions in the combined fields of atmospheres, oceans, and land. GeoSpec is a collaboration of our Laboratory, The Pennsylvania State University, Washington State University, and Research Support Instruments. GeoSpec activities during the current year included final optical prescription and mechanical design, detector procurement, and breadboard assembly plans. Initial testing of the prototype instrument is planned for spring 2006 with validation deployment during the summer at Washington State University.

A commercial Brewer double-grating spectrometer has been modified for nearly continuous measurement of column aerosols, NO_2, and SO_2, by the direct-Sun technique. This instrument has traditionally been used for measurements of total ozone and UV irradiance. Polarization and multiangle measurement capabilities have been added to test the possibility of deriving ozone profiles, as well as particle size and refractive indices of aerosols in the UV. The technology is being transferred to other Brewers around the world to form a network for satellite data validation.

An imaging polarimeter-spectrometer instrument is being developed using internal research and development funds to measure aerosol plume height from space using a passive remote sensing technique developed by the Branch scientists.

A new aircraft-based measurement program was started in 2005. ACAM was test flown onboard the NASA WB-57 during the AVE in June of 2005 flying out of Houston, Texas. This system combines high resolution photographic imagery of both nadir and forward-looking cloud conditions with nadir UV and VIS spectographic measurements in order to map trace gas concentrations of NO_2, O_3, and aerosols. These measurements will be used to validate similar measurements from the OMI onboard Aura. The tests flights were successful and led to instrument improvements that have been implemented for the CR-AVE mission in February of 2006.

5.4 Laboratory Highlights

Biomass-burning Aerosols in South East Asia: Smoke Impact Assessment (BASE-ASIA)

Recent studies reveal that large scale biomass burning appears to have an impact on regional climate. Aerosols produced by biomass burning play an important role in determining cloud lifetime and precipitation, hence, altering the regional to global scale radiation and water budgets. The climatology of Southeast Asia is very different from that of Africa and South America. Large scale biomass burning in Southeast Asia causes smoke to interact extensively with clouds during March and April when fires are normally set. Smoke plumes generated from these fires can stretch hundreds of kilometers downwind of the fires. NASA scientists in the Laboratory for Atmospheres (led by Dr. Si-Chee Tsay) are interested in conducting in-depth observations to evaluate the effects of biomass-burning aerosols on aerosol-cloud interactions. Accurately assessing the impact of smoke aerosols requires continuous observations from satellites and networks of ground-based instruments as well as dedicated field experiments utilizing aircraft and ground-based instruments. NASA and the Chulalongkorn University (CU), Thailand, share an interest in strengthening research and education in Earth Sciences by utilizing spaceborne, airborne, and ground-based observations. The Letter of Agreement between NASA and CU has been signed to jointly conduct the BASE-ASIA research project and educational activities from 2006 to 2009.

The objectives of BASE-ASIA are: (1) to characterize and assess the impact of biomass-burning aerosols on Southeast Asian monsoon onset and precipitation (or fresh water distribution) patterns, (2) to understand the effects of biomass-burning aerosols on remote sensing observations, and (3) to provide educational opportunities for regional scientists and graduate students who desire additional training and research experience. Air and ground observations from Thailand during the studied period will be coordinated with data received during the same time periods from NASA's Terra, and A-Train satellites and other satellite data sets of Southeast Asia. The study areas are the Kingdom of Thailand and possibly the vicinity of the Association of South East Asian Nations (ASEAN), members of which include Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

Developments in 3D Radiative Transfer

The Third I3RC workshop was held October 11–14, 2005 at the Leibniz-Institute of Marine Sciences at the University of Kiel (Germany) and partly onboard the vessel *Color Fantasy*. Climate and Radiation Branch members (Robert Cahalan, Alexander Marshak, Lazaros Oreopoulos, and T.Varnai) were among the main organizers of the workshop. This was the third I3RC workshop; the first two workshops were both held in Tucson, Arizona in 1999 and 2000. The I3RC is an international project that compares the performance of 3D radiative transfer codes used in a variety of scientific applications in the atmospheric sciences. I3RC participants come from more than 30 research groups based in several countries. The project is sponsored by the GEWEX Radiation Panel and the International Radiation Commission, and has been jointly funded by the DOE Atmospheric Radiation Measurements Program and by the NASA Radiation Sciences Program.

Goddard's Climate and Radiation Branch delegated six scientists to give presentations at the workshop: Robert Cahalan, Alexander Marshak, Vanderlei Martins, Lazaros Oreopoulos, Tamas Varnai, and Guoyong Wen. L. Oreopoulos and T. Varnai chaired two sessions and A. Marshak also led the final discussion. T. Varnai and G. Wen presented two new I3RC cases, which are based on a broken cloud field observed by several instruments on the Terra satellite, and 3D spread of lidar pulses in optically thick clouds. In addition to the I3RC cases, publicly available 3D radiative transfer codes, approximation methods, cloud stochastic models, and 3D radiative transfer science, in general, were widely discussed. Forty-six people from 10 countries attended the workshop. The results of the workshop were summarized in the paper "New Directions in the Radiative Transfer of Cloudy Atmospheres" recently published in EOS. For further information contact Alexander Marshak (Alexander.Marshak@nasa.gov).

New Book on 3D Radiative Transfer Published

In August, a new book titled "3D Radiative Transfer in Cloudy Atmospheres" was published. Authored by leading 3D radiation scientists from around the world, this 700-page volume contains expert information on many aspects of this highly complex subject. Laboratory radiative transfer experts R. Cahalan, A. Marshak, and W. Wiscombe are among the authors of the book chapters.

For almost a century, scientists relied on simple one-dimensional models to approximate radiant energy exchange in climate simulations; solar and thermal radiation were only allowed to move vertically. This somewhat crude representation of the atmosphere's radiant energy balance was the best approach science had to offer at the time. In this new publication, developments in 3D cloud radiation during the past few decades are assessed and distilled into a textbook-like tutorial, paving the way for a change in the "business as usual" attitude toward 1D approaches.

"It is time to think of 3D theory as the gold standard in atmospheric radiative transfer, rather than as a perturbation of standard 1D theory," wrote authors A. Marshak (Code 613.2) and A. Davis in the preface of the book, for which they also served as editors.

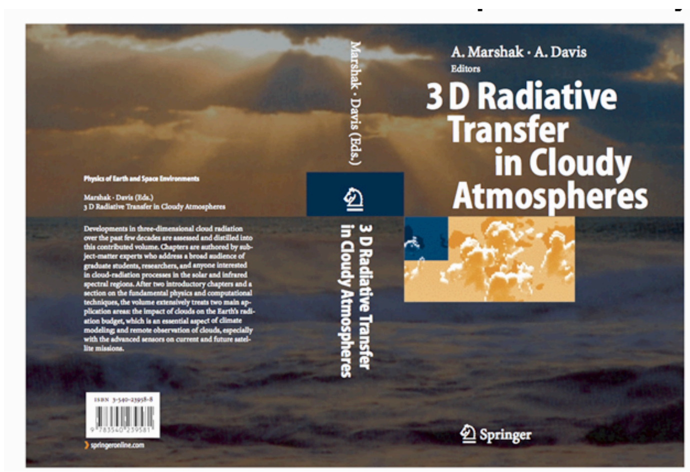


Figure 5.1. Developments in 3-D cloud radiation over the past few decades are assessed and distilled into this volume.

After two introductory chapters and a section on the fundamental physics and computational techniques, the book extensively treats two main application areas: the impact of clouds on the Earth's radiation budget, which is an essential aspect of climate modeling; and remote observation of clouds, especially with advanced sensors on current and future satellite missions. The book, funded in large part by the ARM Program, is written to satisfy a broad audience of graduate students, researchers, and others interested in cloud-radiation processes in the solar and infrared spectral regions. Published by Springer-Verlag (ISBN#3-540-23958-8). For further information contact Alexander Marshak (Alexander.Marshak@nasa.gov).

To see the first nine pages of this book, use the following URL to access the Web version of this report and click on the link given at the end of that section. http://atmospheres.gsfc.nasa.gov/reportsdocs/html/2005/06.php#3D

MODIS Data Processing

The MODIS Atmosphere Team is responsible for generating cloud, aerosol, and clear sky level-2 (pixel-level) and level-2 (gridded) products from the MODIS Terra and Aqua instruments. As a part of the latest MODIS Atmosphere Team reprocessing effort (referred to as “collection 5”), the GSFC level-2 cloud optical and microphysical properties algorithm (thermodynamic phase, optical thickness, effective size, water path) has been largely rewritten. In addition to a number of improvements, the updated algorithm includes new components that have never been incorporated into operational retrievals of this type, including: (1) Pixel-level uncertainties for optical thickness, effective particle size, and water path retrievals, along with estimates of the uncertainty in level-3 gridded means; (2) development of a set of spatially-complete surface spectral albedo maps derived from the MODIS land albedo product and used in modeling above-cloud spectral reflectances; (3) retrievals derived from novel spectral band combinations; and (4) a research-level multilayer cloud detection product. All level-2 retrievals from this algorithm are contained in the MOD06 and MYD06 product files (for MODIS Terra and Aqua, respectively). The algorithm is the responsibility of M.D. King (610) and S. Platnick (613.2), as are the entire set of MODIS Atmosphere Team level-3 (daily, eight-day, and monthly) algorithms.

Collection 5 reprocessing began production in December 2005 with Terra data; MODIS Aqua collection 5 reprocessing is expected to begin in late spring or early summer 2006. The team has developed an extensive Web site (http://modis-atmos.gsfc.nasa.gov/) that provides product documentation, browse imagery, and tools. In particular, documents are provided detailing individual Atmosphere Team collection 5 algorithm modifications, improvements, and impacts. All Atmosphere Team collection 5 products are being processed at GSFC by the MODIS Operations Data Processing System (MODAPS), and will be distributed through the associated MODIS Atmosphere Archive and Distribution System (AADS). The cloud optical and microphysical properties algorithm has also been made available to the University of Wisconsin International MODIS/AIRS Processing Package (IMAPP) team for use with direct broadcast data. For further information contact Steven Platnick (Steven.Platnick@nasa.gov).

CO_2 Lidar

Making range-resolved measurements of CO_2 within the lowest 3000 m of the atmosphere can significantly enhance our understanding of what is happening to anthropogenically generated CO_2, an important greenhouse gas. These measurements enable the direction and magnitude of CO_2 fluxes to be determined, which help identify sources and sinks for the gas. In order to be scientifically useful, the measurement precision must be approximately 1 part in 380. Ground-based lidar observations are capable of providing continuous profiles of CO_2 through the planetary boundary layer and into the free troposphere. We have developed a prototype lidar based on components developed in the telecommunications industry. Our Differential Absorption Lidar (DIAL) approach measures absorption by CO_2 of pulsed laser light at 1.58 μm backscattered from atmospheric aerosols. Aerosol concentrations in the planetary boundary layer are relatively high and will be able to provide adequate signal returns for the desired resolution. Performance simulations indicate that an optimized lidar will be capable of providing continuous 10 min averaged profiles with 150 m vertical resolution and better than 1 ppmv precision at 1 km. Precision increases (decreases) at lower (higher) altitudes and is directly proportional to altitude resolution and acquisition time; thus, precision can be improved if temporal or vertical resolution is sacrificed. The long-term goal of the project is to develop a rugged, autonomous system using only commercially available components that can be replicated inexpensively for deployment in a monitoring network. For further information contact John Burris (John.F.Burris@nasa.gov).

Advances in TRMM Data Analysis

Methods of extracting the dependence of mean rainfall on the time of day have been developed for use with the TRMM data, now available from December 1997 to the present. The method provides not only estimates of the size of the day/night change, but also statistical confidence limits for the changes. The map shown in Figure 5.2 is an example of the information that can be provided for 5° grid boxes, with brightest colors (colors along the top of the color bar) indicating highest confidence in the daily changes. Note how over the oceans maximum rainfall tends to occur in the morning hours, whereas over land it occurs mostly in the afternoon hours. (Grid boxes with average rain rate below 0.01 mm/h have been masked.) For further information contact Tom Bell (Thomas.L.Bell@nasa.gov).

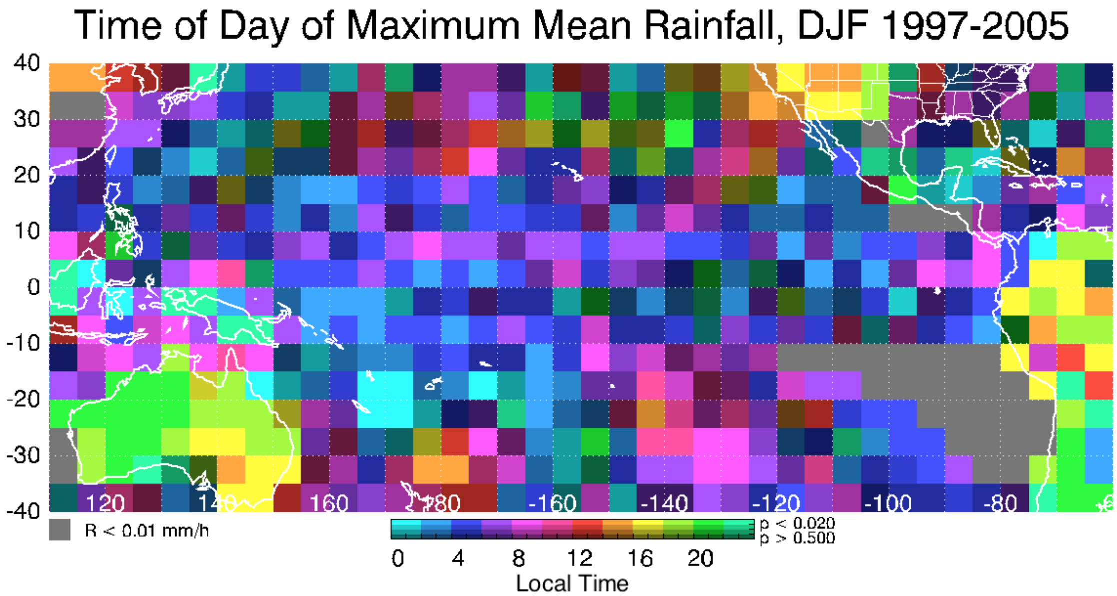


Figure 5.2. Nine year record of time from 1997–2005, of maximum rainfall during December, January, and February.

Radar-Based Wind Measurements from UAVs

While lidar-based tropospheric wind measurements are ideally suited for clear regions, the signal is strongly attenuated by clouds and precipitation. On the other hand, radar-based winds perform well in these regions and are, therefore, very complementary to the lidar measurements. Two separate efforts are being pursued for radar-based winds measurements in precipitation and cloud regions from UAV. The first effort, called UAV Radar (URAD), was started under Goddard IR&D funding. This radar is a conventional X-band radar that performs conical scan from a high-altitude UAV (HUAV). The conical scan provides a means to estimate the atmospheric horizontal winds and radar reflectivity structure in a three-dimensional grid point below the UAV. It also enables estimation of ocean surface winds in rain-free to light-rain regions through well-known scatterometry techniques. The second effort is funded under the NASA IIP and is called HIWRAP. This system also provides similar measurements to URAD, but it is dual-wavelength (Ku and Ka band) and dual incidence angle to provide higher accuracy in the wind measurements. In addition, HIWRAP uses more advanced technology with solid state rather than tube transmitter technology, pulse compression using digital receiver and Field Programmable Gate-Array (FPGA)-based processing. The technology being pursued under this effort also has application to space-based wind measurement. For further information contact Gerry Heymsfield (Gerald.M.Heymsfield@nasa.gov).

Effect of Smoke from African Fires on Shallow Cloud Cover

Clouds developing in a polluted environment tend to have more numerous, but smaller, droplets. This property may lead to suppression of precipitation and longer cloud lifetime. Absorption of solar radiation by aerosols, however, can reduce the cloud cover. The net aerosol effect on clouds is currently the largest uncertainty in evaluating climate forcing. Using large statistics of MODIS satellite data, we indicate, in Figure 5.3, the aerosol effect on shallow water clouds, separately in four regions of the Atlantic Ocean, for June through August 2002: marine aerosol (30°S–20°S), smoke (20°S–5°N), mineral dust (5°N–25°N), and pollution aerosols (30°N–60°N). All four aerosol types effect the cloud droplet size. We also find that the coverage of shallow clouds increases in all of the cases by 0.2–0.4 from clean to polluted, smoky, or dusty conditions. Covariability analysis with meteorological parameters associates most of this change to aerosol, for each of the four regions and 3 months studied. In our opinion, there is low probability that the net aerosol effect can be explained by coincidental, unresolved, changes in meteorological conditions that also accumulate aerosol, or errors in the data. For further information contact Steven Platnick (Steven.E.Platnick@nasa.gov).

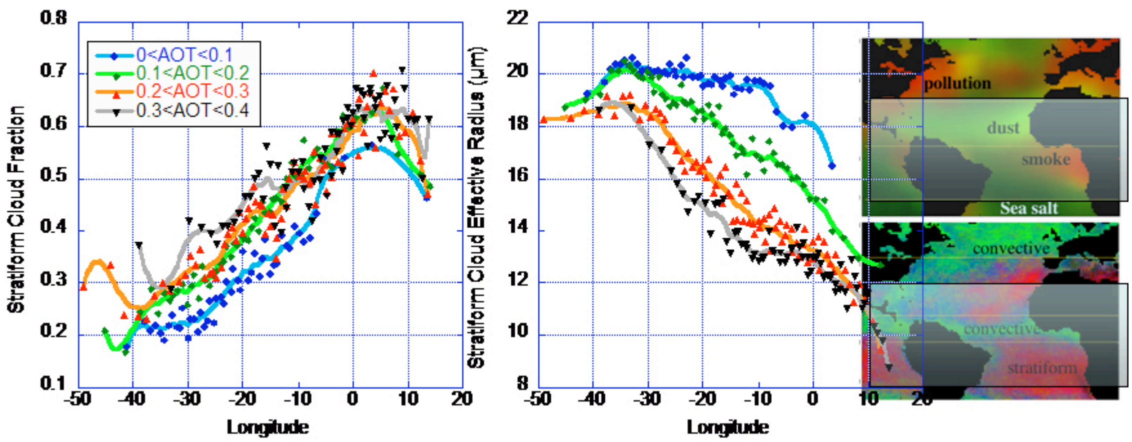


Figure 5.3. Smoke from fires in Africa increases cloud coverage by ~ 0.1 (left panel) while reducing the cloud droplet size (center panel). The effect is linked to smoke inhibition of precipitation and enhancement of the strength of the inversion. The right panel shows the distribution of aerosol and clouds over the Atlantic Ocean for June–August 2002. The upper panel indicates optical thickness, given by the image brightness, and type, given by color. The lower panel shows the distribution of shallow (red), deep convective (green), and mixed (blue) cloud cover. AOT is aerosol optical thickness.

Cloud-Aerosol Interaction Mission, CLAIM-3D

The effects of aerosols in clouds go all the way from changing Earth's radiative balance, to significant effects on changing precipitation patterns and the intensity of thunderstorms. CLAIM-3D is a proposed satellite mission designed to advance our understanding of cloud and precipitation development by measuring *vertically resolved* cloud microphysical parameters in combination with state-of-the-art aerosol measurements. The CLAIM-3D mission concept uses well-established space technology in a set of innovative measurements that allows simultaneous aerosol and cloud microphysics measurements. The proposed mission has a very unique combination of extended wavelength range (380–12,000 nm), polarization, and multiangle 3D observing geometry, combining properties of several previous satellite missions, as well as adding many new features never flown or even proposed before. It is designed to measure the vertical profile of cloud microphysical properties, and also to combine the best features from previous satellite projects (like the Polarization Detecting Environmental Radiometer [POLDER], MISR, MODIS, and OMI) to characterize aerosols and cloud microphysics with greater synergy than any previous mission. The mission will have flexibility in terms of pointing capability in order to focus on cloud types and regions of particular interest, and also to maximize proper illumination geometry for accurate retrievals of cloud microphysical parameters. The multiangle capabilities of CLAIM-3D (along and cross track) allow us optimized geometry to focus on very specific cloud structures and regions. The combination between polarization and high resolution multiangle capability also allows CLAIM-3D to measure "cloud droplet rainbows" or cloud bows, which are just like the rainbows that we see out of rain droplets (of millimeters to a fraction of millimeters in diameter), but now formed by much smaller cloud droplets (of a few micrometers in size). The cloud bow measurements will allow us to accurately measure the size of cloud droplets. This is very important for the understanding of cloud microphysical properties and the evolution towards precipitation. For further information contact Jose Martins (Jose.Martins.1@gsfc.nasa.gov),

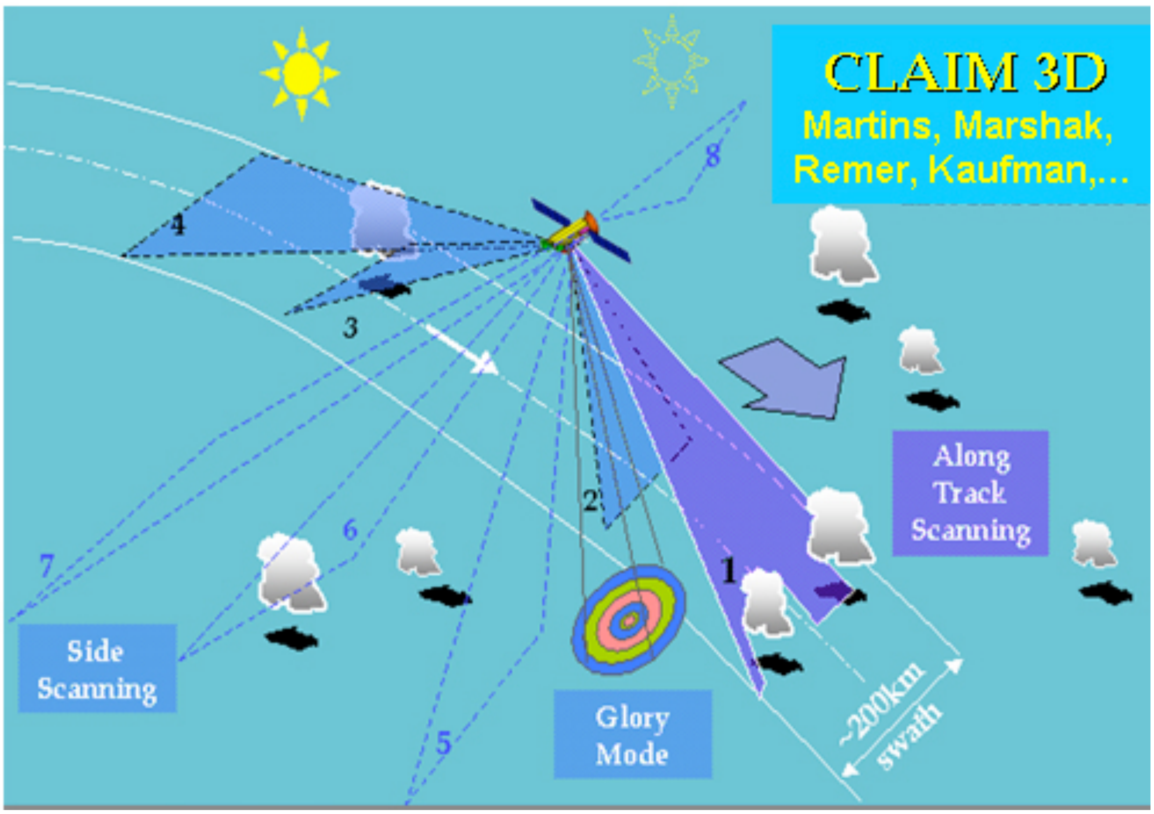


Figure 5.4. Schematic of CLAIM-3D observation modes.

Awards

NASA Exceptional Achievement Medal

Dr. Mian Chin (613.3)
In recognition of the development of the GOCART model to study atmospheric aerosols and gas species and their impact on air quality and climate.

Dr. Yogesh Sud (613.2)
For truly pioneering scientific advances on land-surface parameterization and biospheric-atmospheric processes and their influence on the general circulation.

Barry M. Goldwater Award

On Thursday, June 9, Fritz Hasler, who recently retired from 613.1, was awarded the "Barry M. Goldwater Award" by the American Institute of Aeronautics and Astronautics, Inc. (AIAA) National Capitol Section, which includes about half of all AIAA members. This is a prestigious award that was started at Barry Goldwater's instigation. He was an avid space enthusiast and supporter. The award was presented by Dr. Mike Griffin, NASA Administrator, and past recipient of the same award.

IEEE Senior Member

The Institute of Electrical and Electronics Engineers (IEEE) elevated Chuck Cote to the grade of Senior Member, their highest professional grade.

Dr. Robert Cahalan (613.2)

Dr. Cahalan received an award for "Outstanding Leadership and Service" in recognition of his work as Chair of the Observations Working Group of the United States Climate Change Science Program. The award was presented by James Mahoney, Assistant Secretary of Commerce for Oceans and Atmospheres.

Group Achievement Awards

Aura Education Outreach Team

For implementation of an outstanding education and outreach effort to inspire the next generation of explorers.

Aura Project Science Team

For outstanding and innovative efforts in leading the Earth Observing System Aura Science Team, developing the Aura validation plan, and production of outreach materials.

SAGE Ozone Loss Validation Experiment (SOLVE)-II DC-8 Science Team

In recognition of exceptional scientific achievement during the highly successful SOLVE-II polar mission during the winter of 2002–2003.

Outstanding Teamwork Award

MODIS Aerosol Algorithm Team/Code 613—**Lorraine Remer** accepting for team.
Members of the team include: Allen Chu, Richard Hucek, Charles Ichoku, Richard Kleidman, Robert Levy, Rong-Rong Li, Vanderlei Martins, Shana Mattoo, and Bill Ridgway.

Excellence in Outreach Award

Earth Observatory Team/Code 613—**Rob Simmon** accepting for team.

Instrument Incubator Program (IIP)

The IIP supports NASA's Science Mission Directorate. The main purpose of the program is to identify, develop, and, where appropriate, demonstrate new measurement technologies to reduce the risk, cost, size, and development time of Earth observing instruments, and/or enable new observation measurements. Five Laboratory scientists were selected as PIs, co-investigators (Co-Is), or collaborators on awards made during 2005 under this program.

Bruce M. Gentry, Code 613.1
TWiLiTE:Tropospheric Wind Lidar Technology Experiment

Gerald M. Heymsfield, Code 613.1
High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

David N. Whiteman, Code 613.1
Airborne Water, Aerosol Cloud and Carbon Dioxide Lidar

Omar Torres (**613.3**) is a Co-I with PI David J. Diner, Jet Propulsion Laboratory for *A High-Accuracy Spectropolarimetric Camera for Aerosol Remote Sensing from Space*

Warren Wiscombe (**613.2**) is a Collaborator with PI Martin G. Mlynczak, Langley Research Center, on *In-situ Net Flux Within the Atmosphere of the Earth*

UARS

UARS was launched by the Space Shuttle *Discovery* (STS-48) on September 12, 1991.

Figure 5.5. Artist's conception of UARS in orbit.

Although launched with a designed mission life of 18 months, UARS made comprehensive measurements of the upper atmosphere for more than 14 years. During this time, UARS provided many scientific accomplishments. Four examples of these follow:
1) Quantification of the relation between chlorine-containing constituents and ozone on a global scale in the stratosphere;
2) Quantification of the solar ultraviolet irradiance and total solar irradiance over more than a solar cycle (~14 years);
3) Quantification of the transport in the stratosphere, mesosphere, and lower thermosphere, including the first satellite measurements of winds in these regions;
4) Long-term (~14 years) measurement of several key constituents (ozone, HCl, HF, H_2O, CH_4, NO, and NO_2) in the stratosphere and mesosphere.

There have been over 1,000 papers published in refereed journals that use UARS observations. The study of these valuable measurements has resulted in a rewrite of our understanding of the physical processes acting within and upon the stratosphere, mesosphere, and lower thermosphere.

Figure 5.7. Cake presenedt at the UARS retirement party.

UARS was retired from service on December 14, 2005.

6. Education and Outreach

6.1 Introduction

NASA's founding legislation directs the Agency to expand human knowledge of Earth and space phenomena and to preserve the role of the United States as a leader in aeronautics, space science, and technology. Throughout the 1990s, however, undergraduate and graduate enrollment and the number of doctorates awarded in science and engineering declined by more than 15%. This trend, along with an aging workforce, places an increasing burden on NASA to maintain its level of achievement in science and technology.

The Laboratory's parent organization, The Earth–Sun Exploration Division (ESED—Code 610), has established a Committee for Education and Public Outreach, which is charged with coordinating these activities across the Division. This is a work in progress and no attempt will presently be made to place the Laboratory's activities in the context of an overarching theme; however, several Laboratory members are also on the ESED committee. Scott Braun, Goran Halusa, Paul Newman, and Lorraine Remer, are all working with David Herring, Program Manager for Education and Outreach, to achieve the Committee's objectives. More information may be found at http://esdepo.gsfc.nasa.gov/index.php.

6.2 Education

Interaction with Howard University and Other Historically Black Colleges and Universities (HBCUs)

Partnerships with Howard University:

A part of NASA's mission has been to initiate broad-based aerospace research capability by establishing research centers at the Nation's HBCUs. The Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA) was established in 1992 at Howard University (HU) in Washington, D.C., as a part of this initiative. It has been a goal of the Laboratory and the Earth–Sun Exploration Division to partner with CSTEA to establish at Howard University (HU)a self-supporting facility for the study of terrestrial and extraterrestrial atmospheres, with special emphasis on recruiting and training underrepresented minorities for careers in Earth and space science.

The Laboratory works closely with HU faculty in support of the Howard University Program in Atmospheric Sciences (HUPAS). HUPAS is the first M.S.- and Ph.D.-granting program in atmospheric sciences at an HBCU and the first interdisciplinary academic program at HU. Scientists from our Laboratory contribute to the HUPAS program as lecturers, advisors to students, and adjunct professors who teach courses. A number of HU students have earned M.S. degrees and are about to earn Ph.D. degrees in atmospheric sciences.

Participation with Howard University on the Beltsville Campus Research Site:

Howard University has for several years been in the process of building a multi-instrument atmospheric research facility at their campus in Beltsville, Maryland. This research facility is part of the NOAA-Howard University Center for Atmospheric Science (NCAS). David Whiteman, Belay Demoz (both Code 613.1), and others from GSFC are assisting in mentoring students and advising with instrument acquisition for the site. One of the main instruments at the site is a world-class Raman lidar built with heavy involvement from Code 613.1. The lidar has begun operations and preliminary work on it was reported at the 2005 annual meeting of the AMS in San Diego. David Whiteman and Belay Demoz helped in the proposing, designing, building, and operating the lidar.

Summer Programs

The Summer Institute in Atmospheric, Hydrospheric, and Terrestrial Sciences was held from June 6–August 12, 2005. The institute is organized by Per Gloersen (614.1) and is hosted by the Earth–Sun Exploration Division (Code 610). It is designed to introduce undergraduate students majoring in all areas of the physical sciences to research opportunities in these areas. After a one-week series of introductory lectures, the students select from a list of research topics and are mentored by a Goddard scientist for a period of nine weeks. At the conclusion of this period, the students give a presentation of their results. Laboratory scientists participating in the institute, students, and research topics are shown in Table 6.1.

Table 6.1. Laboratory Scientists Mentoring Students in the 2005 Summer Institute

Mentor/Code	Student	Topic
Geary Schwemmer 613.1	Ian Brown	Testing Holographic Optical Elements and Instrument Control.
Belay Demoz 613.1	Theresa Inman	Observations of Moisture and Temperature Variability in a Non-convective Dryline.
Charles Ichoku 613.2	Luke Ellison	Visualization and Analysis of Fire Radiative Energy Measurements from MODIS.
Yoram Kaufman 613.2	Kristen Mihalka	Assessing the Transport of Aerosols Around the World.
Yogesh Sud 613.2	Andrea May	Intercomparison of Satellite Observations and GOCART Model Aerosol Data with the Aim of Preparing a Realistic Aerosol Data Set for Use in Climate Models.
Santiago Gasso 613.2	Edward Liske	Characterization of Dust Events in Patagonia Using 15 Years of Weather Observations.
Rob Levy 613.2	Ed Nowottnick	Correlations of MODIS and PM 2.5 Measurements in the Mid-Atlantic Region.
Yaping Zhou 613.3	Ahmed Tawfik	An Analysis of Tropical Cyclone Precipitation Using Satellite Observations.

Figure 6.1. Participants in the 2005 Summer Institute. Per Gloersen is at the left.

AMS Fellowship Winners' Visit:

On June 29, 2005 the Earth–Sun Exploration Division hosted a visit to GSFC by a group of AMS Fellowship Winners. The visit was organized by the Laboratory for Atmospheres and consisted of a morning seminar and an afternoon tour of the HU Beltsville site. The AMS Fellowship Program, established in 1991, has awarded over 200 fellowships to students entering their first year of graduate study in the atmospheric or related oceanic or hydrologic sciences, with the total dollars awarded reaching nearly $3.5 million. The program is designed to attract promising young scientists to the AMS-related sciences and provide adequate funding for their first year, allowing the recipients to focus solely on their studies. The AMS is joined by industry leaders and Federal agencies in sponsoring the fellowships, which carry a $22,000 stipend. NASA sponsors four of these fellowships.

The students, their areas of interest, undergraduate and graduate universities are listed in Table 6.2.

Table 6.2. 2005 AMS Fellowship Winners Visiting GSFC

Name	B. S. Degree	Undergraduate	Graduate
Brian Tang	Atmospheric Science and Applied Mathematics	U. of California, Los Angles (UCLA)	Massachusetts Institute of Technology (MIT)
Ashton Robinson*	Meteorology	Jackson State	U. Oklahoma
Andrew Metcalf	Meteorology	Penn State U.	Penn State U.
Allen Clark Evens	Meteorology	Florida State U.	Florida State U.
Corey Potvin	Meteorology	Lyndon State U.	U. Oklahoma
Matthew Greenstein	Meteorology	Penn State U.	State Univ. of New York, Albany (SUNY-Albany)
Heather Coleman	Atmospheric, Oceanic, and Environmental Science	UCLA	UC-Santa Barbara
Timothy Whitcomb*	Atmospheric Science	U. of Washington	MIT
Nathan Snook	Meteorology	Iowa State U.	U. Oklahoma

* Indicates NASA sponsored fellowship

During the morning seminar, presentations were given by scientists from the Laboratory for Atmospheres (Code 613), the Hydrospheric and Biospheric Sciences Laboratory (Code 614), and the Global Modeling and Assimilation Office (GMAO, Code 610.1)). The agenda consisted of the following:

Welcome and opening remarks
Dr. Marshall Shepherd: Mesoscale Atmospheric Processes Branch (Code 613.1)

“On the Cause of the 1930s Dust Bowl”
Dr. Siegfried Schubert: Global Modeling and Assimilation Office (Code 610.1)

“Hydrospheric Research at Goddard”
Dr. Robert Bindschadler: Hydrospheric and Biospheric Sciences Laboratory (Code 614)

“Two Perspectives on Rainfall: Urban-Induced on Earth, and Methane on Titan”
Dr. Marshall Shepherd: Mesoscale Atmospheric Processes Branch (Code 613.1)

“The Aura Project”
Dr. Anne Douglass: Atmospheric Chemistry and Dynamics Branch (Code 613.3)

“Ozonesonde Networks for Study of Atmospheric Processes, Satellite Validation and Trends”
Ms. Jacquie Witte (SSAI)

Figure 6.2. Dr. Marshall Shepherd (back to camera) in discussion with some of the AMS Fellowship winners during a lunch break.

During the afternoon a tour of the Howard University Beltsville facility was lead by Prof. Demetrius Venable, chairman of the Howard University Physics Department and Prof. Everett Joseph of the same department. The tour agenda was:

1:00–1:15 PM Conference Room
Introduction to Howard University Beltsville Site
(Venable, Joseph)

1:15–1:30 PM Tour of O_3 Lab and Doppler Radar Facility
(O_3 Team)

1:30 – 1:40 PM Walk to Telescope/Tower Site

1:40–2:00 PM Radiation and Sounding Sites
(Nzeffe, Robjhon, Walford)

2:00–2:15 PM Lidar and Telescope
(Venable, Connell, Walford)

2:15–2:30 PM 31 m Tower, Flux Site
(Robjhon, Davis)

2:30–2:45 PM MDE Air Quality Monitoring Site
(Venable, Joseph)

2:45–3:00 PM Return to main building, departure

Other than Profs. Venable and Joseph, Fig. 6 is a photo of those graduate students working on advanced degrees at the Beltsville site.

Figure 6.3. Profs. Venable (cap), Joseph (back to camera), and Howard University graduate students discuss the Doppler Radar installation with AMS Fellowship students at the Beltsville site. The base of the radar tower is visible in the upper right corner of the photograph.

University Education

Laboratory members are active in supporting university education through teaching courses and advising graduate students.

Table 6.3. Courses Taught in 2005

University	Course	Instructor
UMBC	Physics 622, Atmospheric Physics II	Steven Platnick
Howard University	Atmospheric Chemistry II	Richard Stewart
George Mason University	Thermodynamics	Yogesh Sud
UMCP	ESSIC 234, Cycles in the Earth System	Warren Wiscombe
UMCP	METO 401, Global Environmental Problems	Warren Wiscombe

Table 6.4. Graduate Student Advising by Laboratory for Atmospheres Members

Member/Code	Student	Degree	Institution	Thesis Topic or Area
John Burris/613.3	John Outerbridge	Ph.D.	U. Alabama	Measurement of tropospheric ozone with lidar
	Shi Kuang	Ph.D.	U. Alabama	Modeling tropospheric ozone
Belay Demoz and David Whiteman/613.1	Felicita Russo	Ph.D.	UMBC	Lidar measurement of aerosols and clouds
	Antonia Gambacorta	Ph.D.	UMBC	AIRS water vapor retrievals
	Menghs G. Mariam	Ph.D.	UMBC	Not defined
	Segayle Walford	Ph.D.	Howard U.	Lidar boundary layer height characterization
	Rasheen Connel	Ph.D.	Howard U.	Not defined
	Scott Rabenhorst	Ph.D.	UMCP	Mesoscale applications of Raman lidar
David Starr/613.1	Likun Wang	Ph.D.	U. Alaska	Homogeneity of Midlatitude Cirrus Cloud Structural Properties Analyzed from the Extended FARS data set
	Robert Carver	Ph.D.	Penn. State	Understanding Subtropical Anvil Cirrus: A Coupled-Model Study
Joanna Joanna Joiner/613.3	Paul Poli	Ph.D.	UMBC	Assimilation of global positioning system radio occultation measurements into numerical weather forecast systems
Lorraine Remer /613.2	Robert Levy	Ph.D.	UMCP	Development of aerosol retrieval algorithm from satellite for specific use in air quality
	Brian Vant-Hunt	Ph.D.	UMCP	Investigation of aerosol–cloud interactions in the boreal and tropical forests using satellite retrievals
Scott Braun /613.1	Joseph Olson	Ph.D.	SUNY-Stonybrook	Impact of coastal orography on landfalling cold fronts

Mian Chin/613.3	Hongqing Liu	Ph.D.	UMCP	Not determined
Gerry Heymsfield/613.2	Haiyan Jiang	Ph.D.	U. Utah	Microwave studies of rainfall
Peter Colarco/ESSIC	Rebecca Matichuk	Ph.D.	U. Colorado	Optical properties of Southern African biomass burning aerosols
William Lau /613	Massimo Bollasina	Ph.D.	UMCP	Aerosol-monsoon water cycle interactions
	Stephen Chen	Ph.D.	UMCP	Mechanism for forcing of the Pacific High
	Wen Mi	Ph.D.	UMCP	Characteristics of aerosol forcings in East Asia

Laboratory members participate with faculty at several joint centers identifying students whose research interests are shared by a faculty member and a Laboratory scientist. Students are encouraged to visit Goddard and it is anticipated that the Laboratory member will serve on the student's thesis committee. The following table lists students currently supported.

Table 6.5. Graduate Students Supported at the Joint Centers

Student	University	Topic	Advisor/Sponsor
Kevin Mallen	CSU	Radar analyses and studies of precipitation systems	Michael Montgomery (CSU) Scott Braun (GSFC)
Maike Ahlgrimm	CSU	GLAS-derived cloud climatologies	Dave Randall (CSU) Jim Spinhirne/Steve Palm (GSFC)
Chris Danforth	UMCP	Chaos processes in general circulation models/GCMs	David Levermore/Eugenia Kalnay (UMCP) Robert Cahalan (GSFC)
Stephen Penny	UMCP	Innovative numerical methods in geophysical problems	Charles D. Levermore (UMCP) Warren Wiscombe (GSFC)
Felicita Russo	UMBC	Micropulse lidar extinction measurements using Raman lidar	Ray Hoff (UMBC) David Whiteman (GSFC)
Antonia Gambacorta	UMBC	Raman lidar studies of water vapor, cirrus cloud, optical depth, particle size, and ice water content	Ray Hoff (UMBC) David Whiteman (GSFC)

CSU: Colorado State University

UMBC: University of Maryland, Baltimore County

6.3 Open Lecture Series

Distinguished Lecturer Seminar Series

One aspect of the Laboratory's public outreach is a Distinguished Lecturer Seminar Series, which is held each year and is announced to all our colleagues in the area. Most of the lecturers are from outside NASA and this series gives them a chance to visit with our scientists and discuss the latest ideas from experts. The following were the lectures presented in 2005.

January 27: Warren Wiscombe

NASA’s Goddard Space Flight Center, Laboratory for Atmospheres, Greenbelt, MD;

“The Brouhaha over Enhanced Absorption of Sunlight by Clouds: What Went Wrong”

February 10: David Starr

NASA’s Goddard Space Flight Center, Laboratory for Atmospheres, Greenbelt, MD;

“Current Issues in Cirrus Cloud Microphysics”

February 24: Tom Ackerman

DOE Atmospheric Radiation Measurement (ARM) Program, Pacific Northwest National Laboratory, Richland, WA;

“Ground-based Measurements of the Atmosphere: The ARM Experience”

March 24: Ralph Kahn

NASA’s Jet Propulsion Laboratory / Caltech;

“What MISR Multi-Angle Imaging Contributes to Our Picture of Atmospheric Aerosols”

May 19: Donald Blake

Department of Chemistry, University of California, Irvine;

“Chinese Urban VOCs, Enhanced Alkanes Throughout the Rural Southwest United States, and Preliminary Bresdth Study Results”

June 15: Graham Feingold

NOAA Environmental Technology Laboratory;

“How Can We Understand the Causes of the Variations of Earth’s Global Energy and Water Cycle”

August 17: Dave Randall

Department of Atmospheric Science, Colorado State University;

“Counting the Clouds”

September 15: Bill Frank

Penn State University, Department of Meteorology;

“A Global Look at Waves and Tropical Cyclogenesis”

November 3: V. Ramanathan

Scripps Institution of Oceanography, University of California at San Diego;

“Global and Regional Climate Changes: The Next Few Decades”

December 2: Robert A. Houze, Jr.

University of Washington;

“Deep Convection in the Asian Monsoon”

6.4 Project Outreach

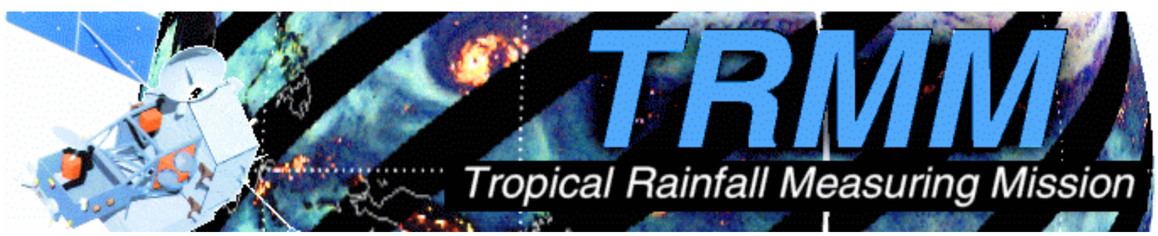
Funded projects in which Laboratory members participate contain elements of both education and public outreach that are described on the project Web sites. Some of these outreach efforts are summarized in the following sections.

TERRA

The EOS Terra outreach effort—under the direction of Yoram Kaufman (Code 613.2), Jon Ranson (Code 614.4), and David Herring (Code 613.2) is a coordinated effort to foster greater cooperation and synergy among the various outreach groups within the EOS community. The Terra mission is designed to improve understanding of the movements of carbon and energy throughout Earth's climate system.

The "About Terra" link on the TERRA home page (http://terra.nasa.gov) contains links to five tutorials designed to inform the public about the importance of the physical parameters observed by the instruments aboard the Terra spacecraft. These tutorials deal with the properties of aerosols, changes in cloud cover and land surface, the Earth's energy balance, and the role of the oceans in climate change. The home page also contains 14 direct links to topics maintained by the Earth Observatory, an outreach site of the Committee for Education and Public Outreach. These links discuss a wide range of topics including Antarctica, flood plains, glaciers, air pollution, and volcanoes discussing each in the context of Terrra observations and why such observations are important.

TRMM

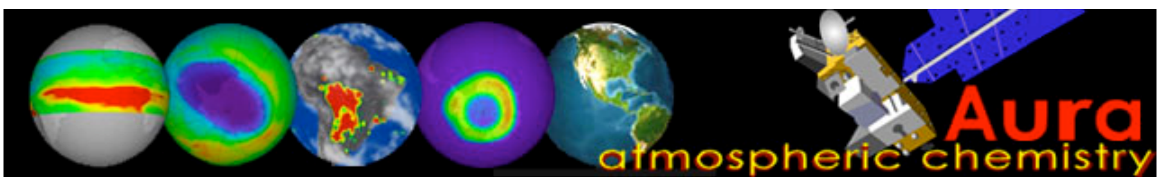


TRMM is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. TRMM continues its comprehensive Education/Outreach program, in which Laboratory personnel promote TRMM science and technology to the public under the leadership of TRMM Project Scientist Robert Adler (613), and TRMM Education and Outreach Scientist Jeffrey Halverson (613.1/UMBC). TRMM has also included the development of broadcast visuals and educational curriculum in its outreach activities. The Educational Resources link on the TRMM home page leads to five problem-based classroom modules in PDF format. These manuals are titled "Investigating the Climate System" and consist of tutorials on clouds, winds, precipitation, weather, and energy. The first four are appropriate for students in grades 5–8, the last is directed at students in grades 9–12. These packages are available on the TRMM Web site (http://trmm.gsfc.nasa.gov/) and have been reviewed as a part of the Earth Science Enterprise (ESE) Education product review. There are also 11 educational videos that give brief tutorials on various aspects of the TRMM project and on the atmosphere's water and energy cycles.

Global Precipitation Measurement (GPM)

The GPM is a follow-on and expanded mission of the current ongoing TRMM. GPM is one of the Earth Observation Satellite programs, mainly initiated by JAXA, the National Institute of Information and Communications Technology (NICT) and NASA. Both the 'Science' and 'Public Outreach' links on the GPM Web site (http://gpm.gsfc.nasa.gov/index.html) contain a wealth of educational materials. The Science page begins with a tutorial, 'The Science of Measuring Precipitation: Why It Matters' that is followed by links to seven additional discussions of the satellite, its instruments, and what will be measured.

EOS Aura



The Aura satellite was launched from Vandenberg AFB on July 15, 2004. The Laboratory for Atmospheres has responsibility for conducting the Education and Public Outreach program for the EOS Aura mission. Aura's Education and Public Outreach program has four objectives:

(1) Educate students about the role of atmospheric chemistry in geophysics and the biosphere;

(2) Enlighten the public about atmospheric chemistry and its relevance to the environment and their lives;

(3) Inform geophysics investigators of Aura science, and thus, enable interdisciplinary research; and

(4) Inform industry and environmental agencies of the ways Aura data will benefit the economy and contribute to answering critical policy questions regarding ozone depletion, climate change, and air quality.

To attain these objectives, the Aura project supports a strong educational and public outreach effort through formal and informal education partnerships with organizations that are leaders in science education and communication. Our partners include the Smithsonian Institution's National Museum of Natural History (NMNH), the American Chemical Society (ACS), and the Global Learning and Observations to Benefit the Environment (GLOBE) Program. Our goals are to educate students and the public and inform industry and policy makers how Aura will lead to a better understanding of the global environment.

NMNH, working with Aura scientists, will design and create an interactive exhibit on atmospheric chemistry as part of its Forces of Change program. NMNH will convey the role that atmospheric chemistry plays in people's lives through the use of remote sensing visualizations and museum objects.

The ACS has produced special issues of the publication *ChemMatters*. These issues will focus on the chemistry of the atmosphere and various aspects of the EOS Aura mission. The special editions of *ChemMatters* will reach approximately 30,000 U.S. high school chemistry teachers and their students.

The Globe Program (Global Learning and Observations to Benefit the Environment) is a worldwide network of students, teachers (10,000 schools in over 95 countries), and scientists working together to study and understand the global environment. Drexel University's (Philadelphia, PA) ground-based instruments will measure ultraviolet-A (UV-A) radiation and aerosols to support measurements taken from the Aura spacecraft. A tropospheric ozone measurement developed by Langley Research Center is also a GLOBE protocol.

Aura's Education and Project Outreach program will also be present at science and environmental fairs and science and technology conferences to demonstrate how Aura fits in to NASA's program to study the Earth's environment.

TOMS

The Atmospheric Chemistry and Dynamics Branch is committed to quality scientific education for students of all ages and levels. The TOMS Web site contains resource materials for science educators at http://toms.gsfc.nasa.gov/teacher/teacher.html. Three lessons that make use of TOMS data and that study the uses of Earth-orbiting satellites are presented at this site. One of these is directed at students in grades 5–8, others are directed to those in grades 9–12. There is also a link to five projects for independent research, which allow advanced students to learn more about atmospheric chemistry and dynamics.

There is also an online textbook at http://www.ccpo.odu.edu/SEES/ozone/oz_class.htm written by Branch scientists and was designed as an educational resource for the general public, as well as for students and educators. This book contains 12 chapters covering all aspects of the science of stratospheric ozone. Each chapter has numerous low- and high-resolution figures, and ends with a set of review questions.

A TOMS Engineering Model is part of a permanent exhibit entitled "Change is in the Air" at the Smithsonian's NMNH. This exhibit explores the interactions between atmospheric chemistry and climate, emphasizing ozone trends in the stratosphere and the effects of degrading air quality on the environment.

7. ACRONYMS

3DRT 3-D	Radiative Transfer
AADS	Atmosphere Archive and Distribution System
ACAM	Airborne Compact Atmospheric Mapper
ACE-Asia	Aerosol Characterization Experiment–Asia
ACS	American Chemical Society
AERONET	Aerosol Robotic Network
AGU	American Geophysical Union
AIAA	American Institute of Aeronautics and Astronautics, Inc.
AirGLOW	Air Goddard Lidar Observatory for Winds
AIRS	Atmospheric Infrared Sounder
AMMA	African Monsoon Multidisciplinary Analysis
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	AMSR Earth Observing System (EOS)
AMSU	Advanced Microwave Sounding Unit
AOML	Atlantic Oceanographic and Meteorological Laboratory
AOT	Aerosol Optical Thickness
ARC	Ames Research Center
ARM	Atmospheric Radiation Measurement (Program)
ARM CART	ARM Cloud and Radiation Test Bed
AROTAL	Airborne Raman Ozone, Temperature, and Aerosol Lidar
ASEAN	Association of South East Asian Nations
AT Lidar	Aerosol and Temperature Lidar
ATMS	Advanced Technology Microwave Sounder
AVE	Aura Validation Experiment
AVHRR	Advanced Very High Resolution Radiometer
BASE-ASIA	Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment
Brewer UV	Brewer Ultraviolet Spectrometer
BUV	Backscatter Ultraviolet
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAMEX	Convection And Moisture EXperiment
CCSP	Climate Change Science Program
CERES	Clouds and the Earth's Radiant Energy System
CFCs	Chlorofluorocarbons
CIMSS	Cooperative Institute of Meteorological Satellite Studies
CLAIM-3D	3D-Cloud Aerosol Interaction Mission
CLIVAR	Climate Variability and Predictability Programme
CNES	*Centre Nationale d'Etude Spatiales*
Co-I	Co-Investigator
COMMIT	Chemical, Optical, and Microphysical Measurements of *In situ* Troposphere
COVIR	Compact Visible and Infrared Radiometer
CPL	Cloud Physics Lidar
CR-AVE	Costa Rica AVE
CrIS	Crosstrack Infrared Sounder

CRS	Cloud Radar System
CSTEA	Center for the Study of Terrestrial and Extraterrestrial Atmospheres
CTM	Chemical Transport Model
CU	Chulalongkorn University
DAAC	Distributed Active Archive Center
DDF	Director's Discretionary Fund
DFRC	Dryden Flight Research Center
DIAL	DIfferential Absorption Lidar
DLR	*Deutsches Zentrum für Luft und Raumfahrt* (German Aerospace Center)
DOAS	Differential Optical Absorption Spectroscopy
DOE	Department of Energy
DOI	Digital Object Identifiers
DSCOVR	Deep Space Climate Observatory Project (formerly Triana)
DU	Dobson Unit
ECMWF	European Centre for Medium-Range Weather Forecasts
EDOP ER-2	Doppler Radar
ENSO	El Niño Southern Oscillation
EnviSat	Environmental Satellite
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EPA	Environmental Protection Agency
EPIC	Earth Polychromatic Imaging Camera
EP-TOMS	Earth Probe TOMS
ERBE	Earth Radiation Budget Experiment
ESE	Earth Science Enterprise
ESED	Earth–Sun Exploration Division
ESMF	Earth Science Modeling Framework
ESRL	Earth System Research Laboratory (NOAA)
ESSIC	Earth System Science Interdisciplinary Center
ESTO	Earth Science Technology Office
ESTO/ACT	Earth Science Technology Office/Advanced Component Technologies
E-Theater	Electronic Theater
FOV	Field of View
FPGA	Field Programmable Gate-Array
FPPA	Field Programmable Processor Array
FvGCM	Finite volume GCM
GCE	Goddard Cumulus Ensemble model
GCM	General Circulation Model
GEOS	Goddard Earth Observing System
GeoSpec	Geostationary Spectrograph
GEST	Goddard Earth Sciences and Technology Center
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GISS	Goddard Institute for Space Studies
GLAS	Geoscience Laser Altimeter System
GLOBE	Global Learning and Observations to Benefit the Environment
GLOW	Goddard Lidar Observatory for Winds

GMAO	Global Modeling and Assimilation Office
GMI	Global Modeling Initiative
GOCART	Global Ozone Chemistry Aerosol Radiation Transport
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center
GSWP	Global Soil Wetness Project
GV	Ground Validation
GVP	Ground Validation Program
HALOE	Halogen Occultation Experiment
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment
HBCUs	Historically Black Colleges and Universities
HIRDLS	High Resolution Dynamics Limb Sounder
HIRS	High Resolution Infrared Sounder
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
HOE	Holographic Optical Element
HRD	Hurricane Research Division
HRDI	High Resolution Doppler Image
HSB	Humidity Sounder Brazil
HU	Howard University
HUAV	High-altitude UAV
HUPAS	Howard University Program in Atmospheric Sciences
HY-SiB	Hydrology and Simple Biosphere
I3RC	Intercomparison of 3D Radiation Codes
IAHS	International Association of Hydrological Sciences
IAMAS	International Association of Meteorology and Atmospheric Sciences
ICCS	International Conference on Conceptual Structures
IEEE	Institute of Electrical and Electronics Engineers
IIP	Instrument Incubator Program
IMAPP	International MODIS/AIRS Processing Package
IMN	*Instituto Meteorologico Nacionale* (Costa Rica)
IMPROVE	Interagency Monitoring of Protected Visual Environments
IORD	Integrated Operational Requirements Document
IPCC	Integovernmental Panel on Climatic Change
IPO	Integrated Program Office
IR	Infrared
IRAD/IR&D	Independent Research and Development
ISAS	Institute of Space and Aeronautical Science (Japan)
ISCCP	International Satellite Cloud Climatology Project
ISIR	Infrared Spectral Imaging Radiometer
JAXA	Japan Aerospace Exploration Agency
JCET	Joint Center for Earth Systems Technology
JCOSS	Joint Center for Observation System Science
JCSDA	Joint Center for Satellite Data Assimilation
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center

KILT	Kiritimati Island Lidar Trailer
L2-SVIP	Lagrange-2 Solar Viewing Interferometer Prototype
LaRC	Langley Research Center
LIS	Land Information System
LORE	Limb Ozone Retrieval Experiment
LRR	Lightweight Rainfall Radiometer
LRR-X	LRR-X band
McRAS	Microphysics of Clouds with the Relaxed Arakawa-Schubert Scheme
MISR	Multi-Angle Imaging Spectroradiometer
MIT	Massachusetts Institute of Technology
MJO	Madden-Julian Oscillation
MLS	Microwave Limb Sounder
MLT	Mesosphere-Lower Thermosphere
MMF	Multimodel Framework
MM5	Mesoscale Model 5
MODAPS	MODIS Operations Data Processing System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOZART	Model for Ozone and Related Chemical Tracers
MPL	Micro-Pulse Lidar
MPLNET	Micro-Pulse Lidar Network
MSU	Microwave Sounding Unit
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency
NCAR	National Center for Atmospheric Research
NCAS	NOAA Center for Atmospheric Science (part of Howard University)
NCEP	National Center for Environmental Prediction
NESDIS	National Environmental Satellite Data and Information Service
NICT	National Institute of Information and Communications Technology
NIIEM	Russian Scientific Research Institute of Electromechanics
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NMNH	National Museum of Natural History
NMS	Neutral Mass Spectrometer
NOAA	National Oceanic and Atmospheric Administration
NOAH	National Centers for Environmental Prediction, Oregon State University, Air Force, Hydrologic Research Lab of the NWS
NPOESS	National Polar Orbiting Environmental Satellite System
NPP	NPOESS Preparatory Project
NRC	National Research Council
NSF	National Science Foundation
OGO	Orbiting Geophysical Observatory
OLR	Outgoing Longwave Radiation
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapper and Profiler System
OOAT	Ozone Operational Algorithm Team

PAVE	Polar Aura Validation Experiment
PHASERS	Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing
PI	Principal Investigator
POES	Polar Orbiting Environmental Satellite
POLDER	Polarization Detecting Environmental Radiometer
QuikSCAT	(NASA's) Quick Scatterometer satellite
QWIP	Quantum Well Infrared Photodetectors
RASL	Raman Airborne Spectroscopic Lidar
RCDF	Radiometric Calibration and Development Facility
RDPP	Reconfigurable Data Path Processor
RFP	Request for Proposal
RMS	Root mean Squared
SAGE	Stratospheric Aerosol and Gas Experiment
SBIR	Small Business Innovative Research
SBUV	Solar Backscatter Ultraviolet
SBUV/2	Solar Backscatter Ultraviolet/version 2
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SDS	Scientific Data Set
SEB	Source Evaluation Board
ShADOE	Shared Aperture Diffractive Optical Element (telescope)
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SOAT	Sounder Operation Algorithm Teams
SOLSE/LORE	Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment
SOLSTICE	Solar/Stellar Irradiance Comparison Experiment
SOLVE	SAGE III Ozone Loss and Validation Experiment
SORCE	SOlar Radiation and Climate Experiment
SPIE	Society of Photo-Optical Instrumentation Engineers
SRL	Scanning Raman Lidar
SSAI	Science Systems and Applications, Inc.
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSI	Spectral Solar Irradiance
SSM/I	Special Sensor Microwave Imager
SSU	Spectral Sensor Unit
STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SVIP	Solar Viewing Interferometer Prototype
TCSP	Tropical Cloud Systems and Processes
THOR	cloud THickness from Offbeam Returns
TIROS	Television Infrared Observation Satellite
TMPA	TRMM Multi-satellite Precipitation Analysis
TOGA-COARE	Tropical Ocean Global Atmosphere–Coupled Ocean Atmosphere Response Experiment
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
TSI	Total Solar Irradiance

TWiLiTE	Tropospheric Wind Lidar Technology Experiment
UAE^2	United Arab Emirates Unified Aerosol Experiment
UARS	Upper Atmosphere Research Satellite
UAV	Unmanned Aerial Vehicle
UCLA	University of California, Los Angeles
UMAD	Uncooled Microbolometer Array Detector
UMBC	University of Maryland, Baltimore County
UMCP	University of Maryland, College Park
URAD	UAV Radar
UTC	Universal Coordinated Time
UV	Ultraviolet
UV-B	Ultraviolet-B radiation
VINTERSOL	Validation of International Satellites and study of Ozone Loss
VIS	Visible
WCRP	World Climate Research Programme
WINDII	Wind Imaging Interferometer
WRF	Weather Research and Forecasting

APPENDIX 1. NASA PRESS RELEASES

Jan. 4, 2005 RELEASE: 05-002
NASA WILL OPERATE TRMM SATELLITE THROUGH SPRING 2005

NASA will continue to operate the Tropical Rainfall Measuring Mission (TRMM) spacecraft through spring 2005.

TRMM has yielded significant scientific research data over the past seven years to users around the globe, four years beyond its original design life. TRMM data has aided the National Oceanic and Atmospheric Administration (NOAA) and other users in their scientific research, understanding of rainfall and storm prediction, and by demonstrating its benefits in operational forecasts.

The extension followed release of interim report recommendations today from the National Academy of Science's (NAS) Committee on the Future of the Tropical Rainfall Measuring Mission. The Committee "strongly recommended continued operation of TRMM, at least until such time as a decision on controlled reentry becomes unavoidable."

NASA and NOAA asked the NAS last summer to convene a workshop to advise on the best use of TRMM's remaining spacecraft life; the overall risks and benefits of the TRMM mission extension options; the advisability of transfer of operational responsibility for TRMM to NOAA; any requirement for a follow-on operational satellite to provide comparable TRMM data; and optimal use of Global Precipitation Measurement mission, a follow-on research spacecraft to TRMM, planned for launch at decade's end. The ad hoc expert NAS Committee will issue a final report next summer.

"NASA recognizes the sustained value of TRMM data to the community and appreciates the Academy's thorough and thoughtful consideration of the future of this mission," said Deputy Associate Administrator for Science of NASA's Science Mission Directorate, Dr. Ghassem Asrar. "With this additional mission extension, however, we continue to be vigilant in maintaining our requirement for an eventual safe, controlled re-entry and deorbit of the spacecraft," he said.

Launched in 1997, TRMM was originally designed as a three-year research mission. Following four years of extending TRMM, NASA and its mission partner, the Japan Aerospace Exploration Agency, planned to decommission TRMM and proceed with a safe, controlled deorbit. NASA's extension of TRMM last fall ensured observations through the hurricane season. The extension accommodated a request from NOAA.

For more information about TRMM on the Web, visit:
http://trmm.gsfc.nasa.gov/ For information about NASA and Agency programs on the Web, visit:
http://www.nasa.gov

Jan. 27, 2005 RELEASE: 05-029

INTERNATIONAL SCIENCE TEAM MEASURES ARCTIC'S ATMOSPHERE

An international team of scientists embarked this week on a journey to improve modeling of global-scale air quality and climate change predictions by conducting high quality measurements of the Arctic region's atmosphere.

The Polar Aura Validation Experiment (PAVE) will gather information to validate data from NASA's Aura satellite, launched in July 2004. PAVE is the third in a series of planned Aura validation and science missions. These missions will help understand the transport and transformation of gases and aerosols in the lower atmosphere (troposphere), and their exchange with those in the lower stratosphere, the layer just above the troposphere. PAVE takes place from Jan. 24 to Feb. 9.

"In addition to providing important validation for the various Aura data products, PAVE brings together a full NASA complement of space-based and suborbital measurements to study the atmospheric chemistry and transport of gases and aerosols in this sensitive region of our planet," said Dr. Michael Kurylo, Program Scientist for PAVE, at NASA Headquarters in Washington. "The information from this campaign will aid in understanding how changing atmospheric composition, associated with climate change, might affect the recovery of the Earth's ozone layer that is anticipated to occur over the next several decades," he said.

In particular, PAVE focuses on the Arctic region of the Northern Hemisphere, where winter chemistry has led to significant seasonal reduction of the stratospheric ozone layer in many years, over more than a decade. The ozone layer restricts the amount of the sun's ultraviolet radiation that reaches the Earth. Depletion of this protective layer can have harmful effects on humans and other ecosystems.

NASA's DC-8 flying laboratory and high-altitude balloons are collecting valuable science data, especially on ozone and ozone-destroying chemicals, using a suite of atmospheric remote sensing and "in situ" instruments. The aircraft, operated by NASA's Dryden Flight Research Center, Edwards, Calif., is flying the PAVE mission from Pease International Tradeport, Portsmouth, N.H. Balloons are being launched from the European Sounding Rocket Range (ESRANGE) facility in Sweden.

The study is focusing on obtaining in situ and remote sensing measurements of the arctic region for validation of the Aura satellite. Information gathered during PAVE will be combined with data from Aura to improve modeling of global-scale air quality, ozone and climate change predictions.

Instruments on board the DC-8 are characterizing upper tropospheric and stratospheric gases inside and outside the Arctic polar region to study ozone depletion chemistry. Such flights also permit measurement of the outflow of gases from the North American continent, thereby contributing to an understanding of how regional pollutants are distributed in the hemisphere.

Scientists will make remote sensing measurements (extending many kilometers away from the aircraft) of tropospheric and stratospheric ozone, aerosols, temperature, nitric acid, HCl, ClO and other ozone-related chemicals. These are complemented by measurements of components such as ozone, methane, water vapor, carbon monoxide, nitric acid and nitrous oxide, in the atmosphere immediately surrounding the aircraft.

Major PAVE partners include the University of New Hampshire, Durham; University of California-Berkeley; University of Bremen, Germany; National Center for Atmospheric Research (NCAR), Boulder, Colo.; the U.S. Naval Research Laboratory in Washington; Koninklijk Netherlands Meteorological Institute; and Los Gatos Research, Inc., Mountain View, Calif.

For more information about the Aura mission on the Internet, visit:
http://aura.gsfc.nasa.gov/ For more information about PAVE on the
Internet, visit: http://cloud1.arc.nasa.gov/ave-polar/

May 20, 2005 RELEASE: 05-129
NASA SUCCESSFULLY LAUNCHES ENVIRONMENTAL SATELLITE

NASA successfully launched a new environmental satellite today for the National Oceanic and Atmospheric Administration (NOAA). It will improve weather forecasting and monitor environmental events around the world.

The NOAA-18 (N) spacecraft lifted off at 6:22 a.m. EDT from Vandenberg Air Force Base, Calif., on a Boeing Delta II 7320-10 expendable launch vehicle. Approximately 65 minutes later, the spacecraft separated from the Delta II second stage.

“The satellite is in orbit and all indications are that we have a healthy spacecraft,” said Karen Halterman, the NASA Polar-orbiting Operational Environmental Satellites (POES) Project Manager, Goddard Space Flight Center (GSFC), Greenbelt, Md. “NASA is proud of our partnership with NOAA in continuing this vital environmental mission,” she added.

Flight controllers tracked the launch vehicle’s progress using real-time telemetry data relayed through NASA’s Tracking and Date Relay Satellite System (TDRSS) starting about five minutes after launch. Approximately 26 minutes after launch, controllers acquired the spacecraft through the McMurdo Sound ground station, Antarctica, while the spacecraft was still attached to the Delta II. Spacecraft separation was monitored by the TDRSS.

The solar array boom and antennas were successfully deployed, and the spacecraft was placed in a near-perfect orbit. The satellite was acquired by the NOAA Fairbanks Station, Alaska, 86 minutes after launch and deployments, and a nominal spacecraft power system was confirmed. NOAA-N was renamed NOAA-18 after achieving orbit.

NOAA-18 will collect data about the Earth’s surface and atmosphere. The data are input to NOAA’s long-range climate and seasonal outlooks, including forecasts for El Nino and La Nina. NOAA-18 is the fourth in a series of five Polar-orbiting Operational Environmental Satellites with instruments that provide improved imaging and sounding capabilities.

NOAA-18 has instruments used in the international Search and Rescue Satellite-Aided Tracking System, called COSPAS-SARSAT, which was established in 1982. NOAA polar-orbiting satellites detect emergency beacon distress signals and relay their location to ground stations, so rescue can be dispatched. SARSAT is credited with saving approximately 5,000 lives in the U.S. and more than 18,000 worldwide.

Twenty-one days after spacecraft launch, NASA will transfer operational control of NOAA-18 to NOAA. NASA’s comprehensive on-orbit verification period is expected to last approximately 45 days.

NOAA manages the POES program and establishes requirements, provides all funding and distributes environmental satellite data for the United States. GSFC procures and manages the development and launch of the satellites for NOAA on a cost-reimbursable basis.

NASA’s Kennedy Space Center, Fla., was responsible for the countdown management and launch of the Delta II, which was provided by Boeing Expendable Launch Systems, Huntington Beach, Calif.

For images of the launch, information about NOAA-N and the polar-orbiting satellites, visit:
http://www.nasa.gov/noaa-n
http://goespoes.gsfc.nasa.gov
http://www.noaa.gov
http://nws.noaa.gov

June 16, 2005 MEDIA ADVISORY: M05-098

NASA ANNOUNCES DANGEROUS WEATHER MEDIA CONFERENCE

NASA hurricane researchers are available for a media teleconference at noon EDT, Thursday, June 23 to discuss the month-long Tropical Cloud Systems and Processes (TCSP) mission to Costa Rica.

TCSP starts July 1, and mission scientists expect to observe the genesis of some of the world's most dangerous weather formations in the Pacific Ocean. Five NASA centers, 10 American universities and the National Oceanic and Atmospheric Administration (NOAA) are participating.

For the call-in number, password, Internet site where graphics and other materials will be posted, reporters should call Tomeka Scales at: 202/358-0781, by 5 p.m. EDT, Wednesday.

Briefing Participants:
- Dr. Ramesh Kakar: Weather Focus Area leader for NASA's Science Mission Directorate
- **Dr. Gerry Heymsfield**: cloud radar expert and research meteorologist at NASA's Goddard Space Flight Center, Greenbelt, Md.
- Dr. Edward Zipser: chairman and professor of the Department of Meteorology at the University of Utah, Salt Lake City
- Dr. Frank Marks, director of the Hurricane Research Division for NOAA's Atlantic Oceanographic and Meteorological Laboratory, Miami

For information about TCSP on the Internet, visit:
http://www.nasa.gov/vision/earth/lookingatearth/hurricane_2005.html
or
http://tcsp.nsstc.nasa.gov/tcsp/

July 26, 2005 RELEASE: 05-199

NASA'S GOES-N SATELLITE READY FOR LAUNCH

NASA announced the Geostationary Operational Environmental Satellite-N (GOES-N) is ready to launch. The GOES-N launch window is from 6:23 to 7:01 p.m. EDT, Friday, July 29, 2005. Liftoff is from Space Launch Complex 37, Cape Canaveral Air Force Station, Fla.

GOES-N joins a system of weather satellites that provide timely environmental information to meteorologists and the public. The GOES system graphically displays the intensity, path and size of storms. Early warning of impending severe weather enhances the public's ability to take shelter and protect property.

"NASA is proud to provide this tool for the National Oceanic and Atmospheric Administration's (NOAA) use in weather operations," said Martin Davis. He is the GOES program manager at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Md. The GOES system serves the central and eastern Pacific Ocean; North, Central, and South America; and the central and western Atlantic Ocean.

The system includes GOES-10, 11 and 12. GOES-11 is in an on-orbit storage mode. GOES-N becomes GOES-13 shortly after launch. It will be checked out, stored on-orbit and available for activation should either GOES-10 or 12 fails or exhausts its fuel. The satellite is the first in the GOES N-P series of spacecraft that will continuously observe and measure meteorological phenomena in real time. The series will provide the meteorological community and atmospheric scientists improved observational and measurement data.

GOES-N will be launched on a Boeing Delta IV (4, 2) vehicle under an FAA commercial license. The satellite will be turned over to NASA after a successful checkout is completed by Boeing Space and Intelligence Systems.

NOAA manages the GOES program, establishes requirements, provides all funding and distributes environmental satellite data for the United States.

GSFC procures and manages the development and launch of the satellites for NOAA on a cost reimbursable basis. GSFC also manages the design, development and launch of NOAA satellites. Boeing, acting as lead contractor, built GOES-N.

For more information about the GOES-N mission and program on the Web, visit:
http://www.nasa.gov/goes-n
http://goespoes.gsfc.nasa.gov
http://www.noaa.gov/ For information about NASA and agency programs on the Web, visit:
http://www.nasa.gov/home/index.html

August 24, 2005 RELEASE: 05-231

NASA/NOAA ANNOUNCE MAJOR WEATHER FORECASTING ADVANCEMENT

NASA and the National Oceanic and Atmospheric Administration (NOAA) today outlined research that has helped to improve the accuracy of medium-range weather forecasts in the Northern Hemisphere.

NASA and NOAA scientists at the Joint Center for Satellite Data Assimilation (JCSDA) in Camp Springs, Md., came up with procedures to improve forecasting accuracy. The scientists worked with experimental data from the Atmospheric Infrared Sounder (AIRS) instrument on NASA's Aqua satellite.

They found incorporating AIRS data into numerical weather prediction models improves the accuracy range of experimental six-day Northern Hemisphere weather forecasts by up to six hours, a four percent increase. AIRS is a high-spectral resolution infrared instrument that takes 3-D pictures of atmospheric temperatures, water vapor and trace gases.

The instrument data have officially been incorporated into NOAA's National Weather Service's operational weather forecasts.

"NASA is assisting the world's weather prediction agencies by providing very detailed, accurate observations of key atmospheric variables that interact to shape our weather and climate," said Dr. Mary Cleave, associate administrator for NASA's Science Mission Directorate. "The forecast improvement accomplishment alone makes the AIRS project well worth the American taxpayers' investment."

"This AIRS instrument has provided the most significant increase in forecast improvement in this time range of any other single instrument," said retired U.S. Navy Vice Adm. Conrad C. Lautenbacher, Jr., Ph.D., Undersecretary of Commerce for Oceans and Atmosphere and NOAA administrator.

"Climate and weather forecasts are dependent upon our understanding current global ocean and atmosphere conditions. If we want to be able to predict what the weather will be like in the future, we must adequately define the global conditions today. Satellite data, like AIRS provides, is a vital link for NOAA to continuously take the pulse of the planet."

"A four percent increase in forecast accuracy at five or six days normally takes several years to achieve," said JSCDA Director, Dr. John LeMarshall. "This is a major advancement, and it is only the start of what we may see as much more data from this instrument is incorporated into operational forecast models at NOAA's Environmental Modeling Center."

The European Center for Medium Range Weather Forecasts began incorporating data from AIRS into their operational forecasts in October 2003. The center reported an improvement in forecast accuracy of eight hours in Southern Hemisphere five-day forecasts.

AIRS is the result of more than 30 years of atmospheric research. It is led by Dr. Moustafa Chahine of NASA's Jet Propulsion Laboratory, Pasadena, Calif. AIRS is the first in a series of advanced infrared sounders that will provide accurate, detailed atmospheric temperature and moisture observations for weather and climate applications.

The JCSDA is operated by NOAA, NASA, the U.S. Air Force and Navy. The goals of the center are to accelerate the use of observations from Earth-orbiting satellites to improve weather and climate forecasts, and to increase the accuracy of climate data sets.

For information about AIRS on the Internet, visit:
http://airs.jpl.nasa.gov/
For information about NASA and agency programs on the Internet, visit:
http://www.nasa.gov/home/index.html

August 26, 2005 STATUS REPORT: E05-009

NASA EXPENDABLE LAUNCH VEHICLE STATUS REPORT: E05-009

Mission: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation and CloudSat (CALIPSO/CloudSat) Launch Vehicle: Boeing Delta 7420 w/Dual Payload Attach Fitting (DPAF)Launch Pad: Space Launch Complex 2 (SLC2), Vandenberg Air Force Base, Calif.Launch Date: NET, September 29, 2005

The CloudSat spacecraft was fueled Aug. 14 and the fuel tanks pressurized Aug. 15; CALIPSO was fueled Aug. 24 and the fuel tanks pressurized Aug. 25. CloudSat was mated to the DPAF Aug 23. Installation of the upper half of the DPAF for CALIPSO was completed today. The CALIPSO Mission Readiness Review was today. The CloudSat Mission Readiness Review is scheduled for Thursday, Sept. 1.

As a part of the NASA Earth System Science Pathfinder program, CALIPSO is a collaborative effort with the French space agency Centre National d'Etudes Spatiales, Ball Aerospace, Hampton University, Va. and France's Institut Pierre Simon Laplace.

Ball Aerospace is responsible for CALIPSO's scientific instrument and communications suite, including the lidar and Wide Field Camera. NASA's Launch Services Program at KSC provides government launch services for this mission through Boeing Expendable Launch Systems.

Previous status reports are available on the Web at:
http://www.nasa.gov/centers/kennedy/launchingrockets/status/2005 For information about NASA and agency programs on the Web, visit:
http://www.nasa.gov/home/index.html

September 2, 2005 RELEASE: 05-246
NASA'S SCIENCE RESOURCES HELP AGENCIES RESPOND TO KATRINA

NASA science instruments and Earth-orbiting satellites are providing detailed insight about the environmental impact caused by Hurricane Katrina. Images and data are helping characterize the extent of flooding; damage to homes, businesses and infrastructure; and potential hazards caused by the storm and its aftermath.

NASA, along with academic institutions and partner agencies, is working to ensure the Department of Homeland Security and the Federal Emergency Management Agency (FEMA) have the best available information to aid in responding to this catastrophic event.

NASA's partner agencies in this endeavor include the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the National Geospatial Intelligence Agency, the Environmental Protection Agency, and the U.S. Department of Agriculture.

Coordinated assistance by numerous academic institutions and laboratories working under NASA grants will be employed by the Gulf Coast relief and recovery efforts to provide geospatial information useful to first responders and decision makers.

NASA aircraft are providing detailed observations of the disaster area. The aircraft are taking high-resolution observations that can be used to assess the amount of damage to communities and the environment. For example at the request of USGS in cooperation with FEMA and the Army Corps of Engineers, NASA's Experimental Advanced Airborne Research LIDAR (EAARL) system is surveying the gulf coastline.

The EAARL system, carried on a Cessna 310, surveyed the northern gulf coastline on Thursday. Tomorrow the aircraft is scheduled to fly over the perimeter and surrounding levee around New Orleans to assist in damage assessment of the system.

While making its observations of the land, EAARL has the ability to "see" through vegetation, like trees and shrubs, to view the land underneath. Near the coast it can map the beach surface under water. This will help in the recovery of the shoreline infrastructure; determine hazard areas and environmental loss.

The Terra, Aqua and Tropical Rainfall Measuring Mission (TRMM) satellites have already provided Earth observations for land cover and rainfall. Terra's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is providing data on the magnitude and extent of damage and flooding to the USGS Emergency Response Team through its Earth Resources Observation Systems Data Center in Sioux Falls, S.D.

NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the Terra and Aqua satellites provided images of flooding, pre and post disaster comparisons. Data from NASA's QuikScat satellite was one source of wind observations used by NOAA's Hurricane Research Division to analyze the wind field of the storm and to track its path.

Another NASA satellite in use is the Earth Observing Mission 1 (EO-1). The Advanced Land Imagery (ALI) multispectral instrument on EO-1 provided land use and land cover observations useful in determining hurricane damage areas and in aiding in recovery, response and mitigation.

NASA satellites are used to improve weather predictions, to study climate and natural hazards. The knowledge gained during these missions aids assessment and recovery operations.

For satellite images and additional information on the Web, visit:
http://www.nasa.gov/hurricane
http://www.aoml.noaa.gov/hrd/Storm_pages/katrina2005/wind.html For information about NASA and agency programs on the Web, visit:
http://www.nasa.gov/home

September 15, 2005 RELEASE: 05-261

NASA SATELLITES WILL REVEAL SECRETS OF CLOUDS AND AEROSOLS

Two NASA satellites, planned for launch no earlier than Oct. 26, will give us a unique view of Earth's atmosphere. CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) are undergoing final preparations for launch from Vandenberg Air Force Base, Calif.

CloudSat and CALIPSO will provide a new, 3-D perspective on Earth's clouds and airborne particles called aerosols. The satellites will answer questions about how clouds and aerosols form, evolve and affect water supply, climate, weather and air quality.

CloudSat and CALIPSO employ revolutionary tools that will probe Earth's atmosphere. Each spacecraft carries an "active" instrument that transmits pulses of energy and measures the portion of the pulses scattered back to the instrument.

CloudSat's cloud-profiling radar is more than 1,000 times more sensitive than typical weather radar. It can detect clouds and distinguish between cloud particles and precipitation. "The new information from CloudSat will answer basic questions about how rain and snow are produced by clouds, how rain and snow are distributed worldwide and how clouds affect the Earth's climate," said Dr. Graeme Stephens, CloudSat principal investigator at Colorado State University, Fort Collins, Colo.

CALIPSO's polarization lidar instrument can detect aerosol particles and can distinguish between aerosol and cloud particles. "With the high resolution observation that CALIPSO will provide, we will get a better understanding of aerosol transport and how our climate system works," said Dr. David Winker, CALIPSO principal investigator at NASA's Langley Research Center, Hampton, Va.

The satellites will be launched into a 438-mile circular, sun-synchronous polar orbit, where they will fly in formation just 15 seconds apart as members of NASA's "A-Train" constellation with three other Earth Observing System satellites. The A-Train includes NASA's Aqua and Aura satellites and France's PARASOL satellite.

The usefulness of data from CloudSat, CALIPSO and the other A-Train satellites will be much greater when combined. The combined set of measurements will provide new insight into the global distribution and evolution of clouds that will lead to improvements in weather forecasting and climate prediction.

CloudSat is managed by NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif. The radar instrument was developed at JPL, with hardware contributions from the Canadian Space Agency. Colorado State University provides scientific leadership and science data processing and distribution.

Other contributions include resources from the U.S. Air Force and the U.S. Department of Energy. Ball Aerospace and Technologies Corp. designed and built the spacecraft. A host of U.S. and international universities and research centers provides support to the science team. Some of these activities are contributed as partnerships with the project.

CALIPSO was developed through collaboration between NASA and the French Space Agency, *Centre National d'Etudes Spatiales* (CNES). NASA's Langley Research Center leads the CALIPSO mission and provides science team leadership, systems engineering, payload mission operations, and validation, processing and archiving of data. Langley also developed the lidar instrument in collaboration with the Ball Aerospace and Technologies Corp., which developed the onboard visible camera.

NASA's Goddard Space Flight Center, Greenbelt, Md., provides project management, system engineering support and overall program management. CNES provides a PROTEUS spacecraft developed by Alcatel, the imaging infrared radiometer, payload-to-spacecraft integration and spacecraft mission operations. The Institut Pierre Simon Laplace in Paris provides the imaging infrared radiometer science oversight, data validation and archival. Hampton University provides scientific contributions and manages the outreach program.

For more information on CloudSat and CALIPSO on the Internet, please visit:
http://www.nasa.gov/cloudsat and
http://www.nasa.gov/calipso

APPENDIX 2. REFEREED ARTICLES

This appendix lists all the refereed articles published by Laboratory for Atmospheres members (names in bold type) in 2005. References marked with an asterisk (*) are highlighted in Appendix 3.

613 Senior Staff and Senior Scientists

Frey, M.M., **R.W. Stewart**, J.R. McConnell, and R.C. Bales, 2005: Atmospheric hydroperoxides in West Antarctica: links to stratospheric ozone and atmospheric oxidation capacity, *J. Geophys. Res.,* **110**, D23301, doi:10.1029/2005JD006110.

*Yu, Jin-Yi and **K.-M. Lau**, 2005: Contrasting Indian Ocean SST variability with and without ENSO influence: A coupled atmosphere-ocean GCM study, *Meteorol. Atmos. Phys.*, **90**, 179–191, doi: 10.1007/s00703-004-0094-7.

Lau, K.-M., **K.-M. Kim,** and Y.T. Li, 2005: Interannual variability, global teleconnection and potential predictability associated with the Asian summer monsoon, in *East Asian Monsoon*, C.P. Chang, ed., World Scientific, 153–176**.**

Xue, Y.K., S. Sun, **K.-M. Lau**, J. Ji, I. Poccard, R. Zhang, H. Kang, G.X. Wu, J.C. Shaake, J. Zhang, and Y. Jiao, 2005: Multiscale Variability of the River Runoff System in China and Its Long-Term Link to Precipitation and Sea Surface Temperature, *J. Hydrometeor.*, **6**, 550–570.

***Lau, K.-M.**, H.T. Wu, **Y.C. Sud**, and G.K. Walker, 2005: Effects of cloud microphysics on tropical atmospheric hydrologic processes and intraseasonal variability in the GEOS GCM, *J. Climate*, **18**, 4731–4751.

Lau, K.-M., 2005: Aerosol-hydrologic cycle interaction: a new challenge in monsoon climate research, *WCRP GEWEX Newsletter*, **15**(1), 7–9, 20.

Lau, K.-M. and K.-M. Kim, 2005: Characterizing monsoon systems using CEOP data, *CEOP Newsletter*, **8**, 5–7.

Lau, K.-M., **K.-M. Kim**, and **N. C. Hsu**, 2005: Observational evidence of effects of absorbing aerosols on seasonal-to-interannual anomalies of the Asian monsoon, *CLIVAR Exchanges*, **10**(3), 7–9.

Sittler, E.C., **R.E. Hartle**, A.F. Viñas, R.E. Johnson, H.T. Smith, and I. Mueller-Wodard, 2005: Titan interaction with Saturn's magnetosphere: Voyager 1 results revisited, *J. Geophys. Res.,* **110**, A09302, doi:10.1029/2004JA010759.

Szego, K., Z. Bebisi, G. Erdos, L. Foldy, F. Crary, D J. McComas, D.T. Young, S. Bolton, A.J. Coates, A. M. Rymer, **R.E. Hartle**, E.C. Sittler, D. Reisinfeld, J.J. Bethelier, R.E. Johnson, H.T. Smith, T.W. Hill, J. Vilppola, J. Steinberg, and N. Andre, 2005: The global plasma environment of Titan as observed by Cassini Plasma Spectrometer during the first two close encounters with Titan, *Geophys. Res. Lett.,* **32,** L20S05,doi: 10.1029/2005GL022646.

613.1 Mesoscale Atmospheric Processes Branch

Amitai, E., L. Liao, X. Llort, and R. Meneghini, 2005: Accuracy verification of spaceborne radar estimates of rain rate, *Royal Meteor. Soc. Atmos. Sci. Lett.*, **6,** 2–6 doi: 10.1002/asl.82.

*Burian, S., and **J.M. Shepherd**, 2005: Effects of urbanization on the diurnal rainfall pattern in Houston, *Hydrological Processes: Special issue on rainfall and hydrological processes*, **19,** 1089–1103.

Burian, S. J., **J.M. Shepherd**, and P. Hooshialsadat, 2005: Urbanization impacts on Houston rainstorms, in *Innovative Modeling of Urban Water Systems, Monograph 12*, W. James, ed., 1–22.

Chepfer, H., V. Noel, P. Minnis, D. Baumgardner, L. Nguyen, G. Raga, **M. McGill**, and P. Yang, 2005: Particle habit in tropical ice clouds during CRYSTAL-FACE: Comparison of two remote sensing techniques with in situ observations, *J. Geophys. Res.*, **110,** D16204, doi:10.1029/2004JD005455.

***Demoz, B.**, **D. Starr**, K. Evans, A. Lare, **D. Whiteman, G. Schwemmer**, R. Ferrare, J. Goldsmith, and S. Bisson, 2005: The cold front of 15 April 1994 over central U.S. Part I: Observations, *Mon. Weather. Rev.*, **133**(6), 1525–1543.

Evans, K.F., J.R. Wang, P.E. Racette, and **G. Heymsfield**, 2005: Ice cloud retrievals and analysis with the Compact Scanning Submillimeter Imaging Radiometer and the Cloud Radar System during CRYSTAL FACE, *J. Appl. Meteor.*, **44,** 839–859.

Gao, S, X. Cui, Y. Zhou, X. Li, and **W.-K. Tao**, 2005: A Modeling study of moist and dynamic vorticity vectors associated with two-dimensional tropical convection, *J. Geophys. Res.*, **110** (D17104), doi:10.1029/2004JD005675.

Gebremichael, M., W.F. Krajewski, M.L. Morrissey, **G. Huffman**, and **R. Adler**, 2005: Detailed evaluation of GPCP one-degree daily rainfall estimates over the Mississippi River Basin, *J. Appl. Meteorol.*, **44,** 665–681.

Gu, G., R. Adler, and A. Sobel, 2005: The Eastern Pacific ITCZ during the Boreal Spring, *J. Atmos. Sci.*, **62,** 1157–1174.

*Hart, W., **J. Spinhirne**, S. Palm, and D. Hlavka, 2005: Height distribution between cloud and aerosol layers from GLAS Spaceborne Lidar in the Indian Ocean region, *Geophys. Res. Lett.*, **32** (L22S06), doi: 10.1029/2005GL023671.

Hlavka, D.L., S.P. Palm, W.D. Hart, **J.D. Spinhirne , M.J. McGill, and E.J. Welton**, 2005: Aerosol and cloud optical depth from GLAS: Results and verification for an October 2003 California fire smoke case, *Geophys. Res. Lett.*, **32** (L22S07), doi: 10.1029/2005GL023413.

Hoff, R.M., S. Palm, J.A. Engel-Cox, and **J. Spinhirne**, 2005: GLAS long-range transport observation of the 2003 California forest fire plumes to the Northeastern U.S., *Geophys. Res. Lett.*, **32** (L22S008), doi: 10.1029/2005GL023723.

Jensen, E., L. Pfister, T. Bui, A. Weinheimer, E. Weinstock, J. Smith, J. Pittman, D. Baumgardner, P. Lawson, and **M. McGill**, 2005: Formation of a tropopause cirrus layer observed over Florida during CRYSTAL-FACE, *J. Geophys. Res.*, **110** (D03208), doi:10.1029/2004JD004671.

Lancaster, R., **J.D. Spinhirne**, and S.P. Palm, 2005: Laser pulse reflectance of the ocean surface from the GLAS satellite lidar, *Geophys. Res. Lett.*, **32** (L22S10), doi: 10.1029/2005GL023732.

Larsen, M., A.B. Kostinski, and **A. Tokay**, 2005: Observations and analysis of uncorrelated rain, *J. Atmos. Sci.*, **62** (11), 4071–4083.

Li, J., **W.-K. Tao**, et al., 2005: Comparisons of EOS MLS cloud ice measurements with ECMWF analyses and GCM simulations, *Geophys. Res. Lett.*, **32** (L18710), doi: 10.1029/2005GL023788.

*Li, L., **G.M. Heymsfield**, L. Tian, and P.E. Racette, 2005: Measurements of ocean surface backscattering using an airborne 94-Ghz cloud radar-implication for calibration of the airborne and spaceborne W-band radars, *J. Atmos. Ocean. Tech.*, **22,** 1033–1045.

*Lin, R.-F., and **D.O. Starr**, J. Reichardt, P.J. DeMott, 2005: Nucleation in synoptically forced cirrostratus, *J. Geophys. Res.*, **110** (D8), D08208, doi: 10.1029/2004JD005362.

Mahesh, A., J.R. Campbell, and **J.D. Spinhirne**, 2005: Multi-year measurements of cloud base heights at South Pole by lidar, *Geophys. Res. Lett.*, **32** (L09812), doi:10.1029/2004GL021983.

Mitrescu, C., J. M. Haynes, G. L. Stephens, S. D. Miller, **G. M. Heymsfield**, and **M. J. McGill**, 2005: Cirrus cloud optical, microphysical, and radiative properties observed during the CRYSTAL-FACE experiment: A lidar-radar retrieval system, *J. Geophys. Res.*, **110,** D9 (D09208), doi:10.1029/2004JD005605.

Negri, A., N. Burkardt, J. Golden, **J. Halverson**, **G. Huffman**, M. Larsen, J. McGinley, R. Updike, J. Verdin, and G. Wieczorek, 2005: The Hurricane-Flood-Landslide Continuum, *Bull. Am. Meteor. Soc.*, **86,** 1241–1247.

*Palm, S.P., A. Benedetti, **J.D. Spinhirne**, **W. Hart**, and **D. Hlavka**, 2005: Validation of ECMWF global forecast model parameters using GLAS atmospheric channel measurements, *Geophys. Res. Lett.*, **32** (L22S09), doi:10.1029/2005GL023535.

Palm, S.P., **J.D. Spinhirne**, and A. Benedetti, 2005: Observations of Antarctic polar stratospheric clouds by GLAS, *Geophys. Res. Lett.*, **32** (L22S04), doi:10.1029/2005GL023524.

***Spinhirne, J.**, S.P. Palm, **W.D. Hart**, D. L. Hlavka, and **E.J. Welton**, 2005: Cloud and aerosol measurements from GLAS: Overview of initial results, *Geophys. Res. Lett.*, **32** (L22S03), doi:10.1029/2005GL023507.

Spinhirne, J.D., S.P. Palm, and **W.D. Hart**, 2005: Antarctica cloud cover for October 2003 from GLAS satellite lidar profiling, *Geophys. Res. Lett.*, **32** (L22S05), doi:10.1029/2005GL023782.

Stenchikov, G, **K. Pickering**, A. DeCaria, **W.-K. Tao**, J. Scala, L. Ott, D. Bartels, and T. Matejka, 2005: Simulation of the fine structure of the 12 July 1996 Stratosphere-Troposphere Experiment: Radiation, Aerosols and Ozone (STERAO-A) storm accounting for effects of terrain and interaction with mesoscale flow, *J. Geophys. Res.*, **110** (D14304), doi:10.1029/2004JD005582.

Tokay, A., P. Bashor, and K.R. Wolff, 2005: Error characteristics of rainfall measurements by collocated Joss-Waldvogel disdrometers, *J. Atmos. Ocean. Tech.*, **22,** 513–527.

*Wolff, D., D.A. Marks, **E. Amitai**, B.L. Fisher, D.S. Silberstein, **A. Tokay**, J. Wang, and J.L. Pippitt, 2005: Ground validation for the Tropical Rainfall Measuring Mission (TRMM), *J. Atmos. Ocean. Technol.*, **22,** 365–380.

*Wu, L., and B. Wang, **S.A. Braun**, 2005: Impacts of air-sea interaction on tropical cyclone track and intensity, *Mon. Wea. Rev.*, **133,** 3299–3314.

Wu, Z.-J., and **A. Tokay**, 2005: Are Z-R power-law relations very likely artifacts due to undersampling? *Quart. J. Roy. Meteor. Soc.* **131,** 381–383.

Yuter, S.E., R.A. Houze, Jr., **E.A. Smith**, T.T. Wilheit, and E. Zipser, 2005: Physical Characterization of Tropical Oceanic Convection Observed in KWAJEX, *J. Appl. Meteor.*, **44,** 385–415.

Zeng, X., **W.-K. Tao**, and J. Simpson, 2005: An Equation for Moist Entropy in a Precipitating and Icy Atmosphere, *J. Atmos. Sci.*, **62**(12), 4293–4309.

Zhou, D.K., W.L. Smith, X. Liu, A.M. Larar, H.-L.A. Huang, J. Li, **M.J. McGill**, S.A. Mango, 2005: Thermodynamic and cloud parameter retrieval using infrared spectral data, *Geophys. Res. Lett.*, **32** (L15805), doi:10.1029/2005GL023211.

613.2 Climate and Radiation Branch

*Al-Saadi, J., J. Szykman, R.B. Pierce, C. Kittaka, D. Neil, D.A. Chu, **L. Remer**, L. Gumley, E. Prins, L. Weinstock, C. MacDonald, R. Wayland, F. Dimmick, and J. Fishman, 2005: Improving national air quality forecasts with satellite aerosol observations, *Bull. Am. Met. Soc.*, **86**(9), 1249–1261.

Alpert, P., P. Kishcha, **Y.J. Kaufman**, and R. Schwarzbard, 2005: Global dimming or local dimming? Effect of urbanization on sunlight availability, *Geophys. Res. Lett.*, **32** (L17802), doi:10.1029/GL023320.

Anderson, D.E., and **R.F. Cahalan**, 2005: The Solar Radiation and Climate Experiment (SORCE) Mission for the NASA Earth Observing System (EOS), *Solar Phys.*, **203**(1), 3–6.

Anderson, T.L., R.J. Charlson, N. Bellouin, O. Boucher, **M. Chin**, S.A. Christopher, J. Haywood, **Y.J. Kaufman**, S. Kinne, J.A. Ogren, **L.A. Remer**, T. Takemura, D. Tanre, **O. Torres**, C.R. Trepte, B.A. Wielicki, D.M. Winker, and H. Yu, 2005: A-Train strategy for quantifying direct climate forcing by anthropogenic aerosols, *Bull. Am. Meteorol. Soc.*, **86**(12), 1795–1809.

Baum, B.A., P. Yang, **A.J. Heymsfield**, **S. Platnick**, M.D. King, Y.X. Hu, and S. . Bedka, 2005: Bulk scattering properties for the remote sensing of ice clouds. 2: Narrowband models, *J. Appl. Meteor.*, **44**, 1896–1911.

Brennan, J.I., **Y.J. Kaufman**, **I. Koren**, and R.-R. Li, 2005: Aerosol-cloud interaction—misclassification of MODIS clouds in heavy aerosol, *IEEE Trans. Geosci. Remote Sens.*, **43**(4), 911–915.

Cahalan, R. ., 2005: Effective cloud properties for large-scale models in *3D Radiative Transfer in Cloudy Atmospheres,* A. Marshak and A. Davis, eds., Springer, New York, 686 pp.

Cahalan, R.F., **M. McGill**, J. Kolasinski, **T. Varnai**, and K. Yetzer, 2005: THOR—Cloud Thickness from Offbeam Lidar Returns, *J. Atmos. Ocean. Tech.*, **22**(6), 605–627.

***Cahalan, R.F.**, **L. Oreopoulos**, **A. Marshak**, K.F. Evans, A. Davis, R. Pincus, K. Yetzer, B. Mayer, R. Davies, T. Ackerman, H. Barker, E. Clothiaux, R. Ellingson, M. Garay, E. Kassianov, S. Kinne, A. Macke, W. OHirok, P. Partain, S. Prigarin, A. Rublev, G. Stephens, F. Szczap, E. Takara, **T. Varnai**, G. Wen, and T. Zhuravleva, 2005: The International Intercomparison of 3D Radiation Codes (I3RC): Bringing together the most advanced radiative transfer tools for cloudy atmospheres, *Bull. Amer. Meteor. Soc.,* **86**(9), 1275–1293.

Chu, D.A., **L.A. Remer**, **Y.J. Kaufman**, B. Schmid, J. Redemann, K. Knobelspiesse, J.D. Chern, J. Livingston, P.B. Russell, X. Xiong, and W. Ridgway, 2005: Evaluation of aerosol properties over ocean from Moderate Resolution Imaging Spectroradiometer (MODIS) during ACE-Asia, *J. Geophys. Res.*, **110** (D07308), doi:10.1029/2004/JD005208.

Cuddapah, P., R. Iacovazzi, J.-M. Yoo, and **K.-M. Kim**, 2005: A model for estimation of rain rate on tropical land from TRMM Microwave Imager Radiometer observations, *J. Meteor. Soc. Japan*, **83**(4), 595–609.

Evans, K.F., and **A. Marshak**, 2005: Numerical Methods in *3D Radiative Transfer in Cloudy Atmospheres,* A. Marshak and A. Davis, eds., Springer, New York, 686 pp.

Gatebe, C.K., M.D. King, A.I. Lyapustin, G.T. Arnold, and J. Redemann, 2005: Airborne spectral measurements of ocean directional reflectance, *J. Atmos. Sci.*, **62**, 1072–1092.

Gerard, B., J.-L. Deuze, M. Herman, **Y.J. Kaufman**, P. Lallart, C. Oudard, **L.A. Remer**, B. Roger, B. Six, and D. Tanre, 2005: Comparisons between POLDER 2 and MODIS/Terra aerosol retrievals over ocean, *J. Geophys. Res.*, **110** (D24211), doi:10.1029/2005JD006218.

Hao, W.M., D.E. Ward, R.A. Susott, R.E. Babbitt, B.L. Nordgren, **Y.J. Kaufman**, B.N. Holben, and D.M. Giles, 2005: Comparison of aerosol optical thickness measurements by MODIS, AERONET sun photometers, and Forest Service handheld sun photometers in southern Africa during the SAFARI 2000 campaign, *Inter. J. Remote Sens.,* **26**(19), 4169–4183.

***Ichoku, C.**, and **Y.J. Kaufman**, 2005: A method to derive smoke emission rates from MODIS fire radiative energy measurements, *IEEE Trans. Geosci. Remote Sens.,* **43**(11), 2636–2649.

Ichoku, C., **L.A. Remer**, and T.F. Eck, 2005: Quantitative evaluation and intercomparison of morning and afternoon MODIS aerosol measurements from Terra and Aqua, *J. Geophys. Res.* **110 (**D10S03), doi:10.1029/2004JD004987.

Ignatov, A., P. Minnis, N. Loeb, B. Wielicki, W. Miller, S. Sun-Mack, D. Tanre, **L.A. Remer**, I. Laszlo, and E. Geier, 2005: Two MODIS aerosol products over pcean on the Terra and Aqua CERES SSF datasets, *J. Atmos. Sci.*, **62**, 1008–1031.

Jin, M., R.E. Dickinson, and D.-L. Zhang, 2005: The footprint of urban areas on global climate as characterized by MODIS, *J. Climate*, **18**, 1551–1565.

***Jin, M.**, and **J. M. Shepherd**, 2005: Inclusion of urban landscape in a climate model—How can satellite data help? *Bull. Amer. Meteor. Soc.*, **86**, 681–896.

Jin, M., **J.M. Shepherd**, and M.D. King, 2005: Urban aerosols and their interaction with clouds and rainfall: A case study for New York and Houston, *J. Geophys. Res.*, **110** (D10S20), doi:10.1029/2004JD005081.

***Kaufman, Y.J.**, O. Boucher, D. Tanre, **M. Chin**, **L.A. Remer**, and T. Takemura, 2005: Aerosol anthropogenic component estimated from satellite data, *Geophys. Res. Lett.* **32** (L17804), doi:10/1029/2005GL023125.

Kaufman, Y.J., **I. Koren**, **L.A. Remer**, D. Rosenfeld, and Y. Rudich, 2005: The effect of smoke, dust and pollution aerosol on shallow cloud development over the Atlantic Ocean, *Proc. Nat. Acad. Sci.*, **102**(32), 11,207–11,212.

***Kaufman, Y.J.**, **I. Koren**, **L.A. Remer**, D. Tanre, P. Ginoux, and S. Fan, 2005: Dust transport and deposition observed from the Terra–Moderate Resolution Imaging Spectroradiometer (MODIS) spacecraft over the Atlantic Ocean, *J. Geophys. Res.*, **110** (D10S12), doi:10.1029/2003JDO04436.

Kaufman, Y.J., **L.A. Remer**, D. Tanre, R.-R. Li, R. Kleidman, **S. Mattoo**, **R. Levy**, T. Eck, B.N. Holben, **C. Ichoku**, J. Martins, and **I. Koren**, 2005: A critical examination of the residual cloud contamination and diurnal sampling effects on MODIS estimates of aerosol over ocean, *IEEE Trans. Geosci. Remote Sens.,* **43**(12), 2886–2897.

***Kleidman, R.G.**, N.T. O'Neill, **L.A. Remer**, **Y.J. Kaufman**, T.F. Eck, D. Tauré, O. Dubovick, and B.N. Holden, 2005: Comparison of Moderate Resolution Imaging Spectroradiometer (MODIS) and aerosol robotic network (AERONET) remote-sensing retrievals of aerosol fine mode fraction over ocean, *J. Geophys. Res.*, **110** (D22205), doi:10.1029/2005JD005760.

Knyazikhin, Y., **A. Marshak**, M. Larsen, **W. Wiscombe**, J. Martonchik, and R. Myneni, 2005: Small-scale drop size variability: Impact on estimation of cloud optical properties, *J. Atmos. Sci.*, **62**, 2555–2567.

***Koren, I.**, **Y.J. Kaufman**, D. Rosenfeld, **L.A. Remer**, and Y. Rudich, 2005: Aerosol invigoration and restructuring of Atlantic convective clouds, *Geophys. Res. Lett.*, **32** (LI4828), doi:10.1029/2005GL023187.

Levy, R.C., **L.A. Remer**, J.V. Martins, **Y.J. Kaufman**, A. Plana-Fattori, J. Redemann, P.B. Russell, and B. Wenny, 2005: Evaluation of the MODIS aerosol retrievals over ocean and land during CLAMS, *J. Atmos. Sci.*, **62**, 974–992.

Li, R.-R., **L. Remer**, **Y.J. Kaufman**, **S. Mattoo**, B.-C. Gao, and E. Vermote, 2005: Snow and ice mask for the MODIS aerosol products, *IEEE Geosci. Remote Sens. Lett.*, **2**(3), 306–310.

Mace, G.G., Y. Zhang, **S. Platnick**, M.D. King, P. Minnis, and P. Yang, 2005: Evaluation of cirrus cloud properties derived from MODIS data using cloud properties derived from ground-based observations collected at the ARM SGP site, *J. Appl. Meteor.*, **44**, 221–240.

Marshak, A., and A.B. Davis, 2005: "Scale-by-Scale Analysis and Fractal Cloud Models," in: *3D Radiative Transfer in Cloudy Atmospheres,* A. Marshak and A. Davis, eds., Springer, New York, 686 pp.

Marshak, A., A. Davis, eds., 2005: *3D Radiative Transfer in Cloudy Atmospheres,* Springer, New York, 686 pp.

Marshak, A., Yu. Knyazikhin, M.L. Larsen, and **W.J. Wiscombe**, 2005: Small-scale drop size variability: Empirical models for drop-size-dependent clustering in clouds, *J. Atmos. Sci.*, **62**, 551–558.

Marshak, A, and A.B. Davis, 2005: "Horizontal Fluxes and Radiative Smoothing," in: *3D Radiative Transfer in Cloudy Atmospheres,* A. Marshak and A. Davis, eds., Springer, New York, 686 pp.

Moody, E.G., M.D. King, **S. Platnick**, C.B. Schaaf, and F. Gao, 2005: Spatially complete global spectral surface albedos: Value-Added datasets derived from Terra MODIS land products, *IEEE Trans. Geosci. Remote Sens.*, **43**, 144–158.

Myhre, G., F. Stordal, M. Johnsrud, D.J. Diner, I.V. Geogdzhayev, J.M. Haywood, B. Holben, T. Holzer-Popp, A. Ignatov, R. Kahn, **Y.J. Kaufman**, N. Loeb, J. Martonchik, M.I. Mishchenko, N.R. Nalli, **L.A. Remer**, M. Schroedter-Homscheidt, et al., 2005: Intercomparison of satellite retrieved aerosol optical depth over ocean during the period September 1997 to December 2000, *Atmos. Chem. Physics* **5**, 1697–1719.

Oreopoulos, L., 2005: The impact of subsampling on MODIS Level-3 statistics of optical thickness and effective radius, *IEEE Trans. Geosci. Remote Sens.*, **43**(2), 366–373.

***Oreopoulos, L.**, and **R.F. Cahalan**, 2005: Cloud inhomogeneity from MODIS, *J. Climate,* **18**(23), 5110–5124, doi:10.1175/JCLI3591.1.

Prigarin, S.M., and **A. Marshak**, 2005: Numerical model of broken clouds adapted to observations, *Atmos. Ocean. Opt.*, **18**, 236–242.

Redemann, J., B. Schmid, J.A. Eilers, R. Kahn, **R.C. Levy**, P.B. Russell, J.M. Livingston, P.V. Hobbs, W.L. Smith, and B.N. Holben, 2005: Suborbital measurements of spectral aerosol optical depth and its variability at subsatellite grid scales in support of CLAMS 2001, *J. Atmos. Sci.*, **62**(4), 993–1007.

***Remer, L.A.**, **Y.J. Kaufman**, D. Tanre, **S. Mattoo**, D.A. Chu, J.V. Martins, R.R. Li, **C. Ichoku**, **R.C. Levy**, R.G. Kleidman, T.F. Eck, E. Vermote, and B.N. Holben, 2005: The MODIS aerosol algorithm, products and validation, *J. Atmos. Sci.*, **62**, 947–973.

Shepherd, M., and **M. Jin**, 2005: A Summary of the 2003 Union Session, Human induced climate variations on urban areas: from observations to modeling. *EOS Trans.*, Paper #2004ES000657.

Tanre, D., **Y. Kaufman**, T. Nakajima, and V. Ramanathan, 2005: Preface to special section on Global Aerosol System, *J. Geophys. Res.*, **110**, D10S01, doi:10/1029/2004JD005724.

Vant-Hull, B., Z. Li, B.F. Taubman, **R. Levy**, L. Marufu, F.-L. Chang, B.G. Doddridge, and R.R. Dickerson, 2005: Smoke over haze: Comparative analysis of satellite, surface radiometer, and airborne in situ measurements of aerosol optical properties and radiative forcing over the eastern United States, *J. Geophys. Res.*, **110** (D10S21), doi:10.1029/2004JD004518.

Wiscombe, W.J., 2005: "Scales, Tools and Reminiscences," in: *3D Radiative Transfer in Cloudy Atmospheres,* **A. Marshak** and A. Davis, eds., Springer, New York, 686 pp.

Xue, Y., S. Sun, **K.-M. Lau**, J. Ji, I. Poccard, R. Zhang, H.-S. Kang, G. Wu, J.C. Schaake, J.Y. Zhang, and Y. Jiao, 2005: Multiscale variability of the river runoff system in China and its long-term link to precipitation and sea surface temperature, *J. Hydrometeo.*, **6**(4), 550–570.

Yu, H., **Y.J. Kaufman**, **M. Chin**, G. Feingold, **L.A. Remer**, T. Anderson, Y. Balkanski, N. Bellouin, O. Boucher, S. Christopher, P. DeCola, R. Kahn, D. Koch, N. Loeb, M.S. Reddy, M. Schultz, T. Takemura, and M. Zhou, 2005: A review of measurement-based assessment of aerosol direct radiative effect and forcing, *Atmos. Chem. Phys. Discuss.,* **5**, 7647–7768.

Zhang, J., S.A. Christopher, **L.A. Remer**, and **Y.J. Kaufman**, 2005: Shortwave aerosol radiative forcing over cloud-free oceans from Terra I: Angular models for aerosols, *J. Geophys. Res.*, **110** (D10S23), doi:10.1029/2004JD005008.

Zhang, J., S.A. Christopher, **L.A. Remer**, and **Y.J. Kaufman**, 2005: Shortwave aerosol radiative forcing over cloud-free oceans from Terra II: Seasonal and global distributions, *J. Geophys. Res.*, **110** (D10S24), doi:10.1029/2004JD005009.

Zhou, M., **H. Yu**, R.E. Dickinson, O. Dubovik, and B. Holben, 2005: A normalized description of the direct effect of key aerosol types on solar radiation as estimated from AERONET aerosols and MODIS albedos, *J. Geophys. Res.*, **110** (D19202), doi:10.1029/2005JD005909.

Zhuravleva, T., and **A. Marshak**, 2005: On the validation of the Poisson model of broken clouds, *Izvestiya Atmos. Ocean. Physics*, **6**, 783–797.

Code 613.3 Atmospheric Chemistry and Dynamics Branch

Anderson, T.L., R.J. Charlson, N. Bellouin, O. Boucher, **M. Chin**, S.A. Christopher, J. Haywood, **Y. Kaufman**, S. Kinne, J.A. Ogren, L.A. Remer, T. Takemura, D. Tanre, **O. Torres**, C.R. Trepte, B.A. Wielicki, D. Winker, and H. Yu, 2005: An A-Train strategy for quantifying direct aerosol radiative forcing, *Bull. Am. Meteor.,* **86**, 12, 1795–1809.

Arola, A., S. Kazadzis, **N. Krotkov**, A. Bias, **J. Herman**, and K. Lakkala, 2005: Assessment of TOMS UV bias due to the absorbing aerosols, *J. Geophys. Res*., **110** (D23211), doi:10.1029/2005JD005913.

de Almeida Castanho, A.D., J.V. Martins, P.V. Hobbs, P. Artaxo, L. Remer, M. Yamasoe, and **P.R. Colarco**, 2005: Chemical characterization of aerosols on the East Coast of the United States using aircraft and ground based stations during the CLAMS Experiment, *J. Atmos. Sci.,* **62**, 934–946.

Fromm, M., R. Bevilacqua, R. Servranckx, J. Rosen, J.P. Thayer, **J.R. Herman**, and **D. Larko**, 2005: Pyro-cumulonimbus injection of smoke to the stratosphere: Observations and impact of a super blowup in northwestern Canada on 3–4 August 1998, *J. Geophys. Res.*, **110** (D08205), doi:10.1029/2004JD005350.

Gurney, K.R., Y.-H. Chen, T. Maki, **S.R. Kawa**, **A.E. Andrews**, and **Z. Zhu**, 2005: Sensitivity of atmospheric CO_2 inversions to seasonal and interannual variations in fossil fuel emissions, *J. Geophys. Res.,* **110** (D10308), doi:10.1029/2004JD005373.

Hansen, J., M. Sato, R. Ruedy, L. Nazarenko, A. Lacis, G.A. Schmidt, G. Russell, I. Aleinov, M. Bauer, S. Bauer, N. Bell, B. Cairns, V. Canuto, M. Chandler, Y. Cheng, A. Del Genio, G. Faluvegi, **E. Fleming**, A. Friend, T. Hall, **C. Jackman**, M. Kelley, N. Kiang, D. Koch, J. Lean, J. Lerner, K. Lo, S. Menon, R. Miller, P. Minnis, T. Novakov, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, D. Shindell, P. Stone, S. Sun, N. Tausnev, D. Thresher, B. Wielicki, T. Wong, M. Yao, and S. Zhang, 2005: Efficacy of climate forcings, *J. Geophys. Res.,* **110** (D18104), doi:10.1029/2005JD005776.

Huang, F.T., **H.G. Mayr**, and C.A. Reber, 2005: Intra-seasonal oscillations (ISO) of zonal-mean meridional winds and temperatures as measured by UARS, *Ann. Geophys.,* **23**, 1131.

Irie, H., K. Sudo, H. Akimoto, A. Richter, J. P. Burrows, T. Wagner, **M.Wenig**, S. Beirle, Y. Kondo, V.P. Sinyakov, and F. Goutail, 2005: Evaluation of long-term tropospheric NO_2 data obtained by GOME over East Asia in 1996–2002, *Geophys. Res. Lett.,* **32** (L11810), doi:10.1029/2005GL022770.

***Jackman, C.H**., **M.T. DeLand**, **G.J. Labow**, **E.L. Fleming**, D.K. Weisenstein, M.K.W. Ko, M. Sinnhuber, J. Anderson, and J.M. Russell, 2005: The influence of the several very large solar proton events in years 2000–2003 on the neutral middle atmosphere, *Adv. Space Res.*, **35**(3), 445–450.

Jackman, C.H., **M.T. DeLand**, **G.J. Labow**, **E.L. Fleming**, D.K. Weisenstein, M.K.W. Ko, M. Sinnhuber, and J.M. Russell, 2005: Neutral atmospheric influences of the solar proton events in October–November 2003, *J. Geophy. Res*., **110** (A09S27), doi:10.1029/2004JA01088.

***Joiner, J**., and P. Poli, 2005: Note on the effects of horizontal gradients for nadir-viewing microwave and infrared sounders, *Quart. J. Roy. Meteor. Soc.,* **131**, 1784–1792.

***Kawa, S.R., P.A. Newman, R.S. Stolarski**, and R.M. Bevilacqua, 2005: Fall vortex ozone as a predictor of springtime total ozone at high northern latitudes, *Atmos. Chem. Phys.,* **5**, 1655–1663.

Kazadsis, S., A. Bais, N. Kouremeti, E. Gerasopoulos, K. Garane, M. Blumthaler, B. Schallhart, and **A. Cede**, 2005: Direct spectral measurements with a Brewer spectroradiometer: absolute calibration and aerosol optical depth retrieval, *Appl. Optics*, **44**(9), 1681–1690.

Kinne, S., M. Schulz, C. Textor, S. Guibert, Y. Balkanski, S.E. Bauer, T. Berntsen, T.F. Berglen, O. Boucher, **M. Chin**, W. Collins, F. Dentener, **T. Diehl**, R. Easter, J. Feichter, D/ Fillmore, S. Ghan, **P. Ginoux**, S. Gong, A. Grini, J. Hendricks, M. Herzog, L Horowitz, I. Isaksen, T. Iversen, A. Kirkevåg, S. Kloster, D. Koch, J. E. Kristjansson, M. Krol, A. Lauer, J. F. Lamarque, G. Lesins, X. Liu, U. Lohmann, V. Montanaro, G. Myhre, J. Penner, G. Pitari, S. Reddy, O. Seland, P. Stier, T. Takemura, and X. Tie, 2005: An AeroCom initial assessment—optical properties in aerosol component modules of global models, *Atmos. Chem. Phys. Discuss*., **5**, 8285–8330.

Krotkov, N.A., P.K. Bhartia, J. Herman, J. Slusser, G. Scott, G. Janson, **G. Labow**, T. Eck, and B. Holben, 2005: Aerosol UV absorption experiment (2002–04): 1. UV-MFRSR calibration and intercomparison with CIMEL sun photometers, *Opt. Eng.,* **44**(4), 041004.

Krotkov, N.A., P.K. Bhartia, J. Herman, J. Slusser, G. Scott, **G. Labow**, A. Vasilkov, T. Eck, **O. Dubovik**, and **B. Holben**, 2005: Aerosol UV absorption experiment (2002–04): 2. Absorption optical thickness, refractive index, and single scattering albedo, *Opt. Eng.,* **44**(4), 041005.

Kondragunta, S., L.E. Flynn, A. Neuendorffer, A.J. Miller, C. Long, R. Nagatani, S. Zhou, T. Beck, E. Beach, **R.D. McPeters, R.S. Stolarski, P.K. Bhartia**, **M.T. Deland**, and L.-K. Huang, 2005: Vertical structure of the anomalous 2002 Antarctic ozone hole, *J. Atmos. Sci.*, **62**, 801–811.

LeMarshall, J., J. Jung, J. Derber, R. Treadon, S.J. Lord, M. Goldberg, W.Wolf, H.C. Liu, **J. Joiner**, J. Woollen, R. Todling, and R. Gelaro, 2005: Impact of atmospheric infrared sounder observations on weather forecasts, *Eos*, **86**, 109–116.

LeMarshall, J., J. Jung, J. Derber, R. Treadon, S.J. Lord, M. Goldberg, W. Wolf, H.C. Liu, J**. Joiner**, J. Woollen, R. Todling, P. van Delst, and Y. Tahara, 2005: AIRS hyperspectral data improves Southern Hemisphere forecasts, *Austral. Meteor. Mag.,* **54**, 57–60.

Lopez-Puertas, M., B. Funke, S. Gil-Lopez, T. von Clarmann, G. P. Stiller, M. Hopfner, S. Kellmann, H. Fischer, and **C.H. Jackman**, 2005: Observations of NO_x enhancement and ozone depletion in the Northern and Southern Hemispheres after the October–November 2003 solar proton events, *J. Geophys. Res*., **110** (A09S43), doi:10.1029/2005JA011050.

Lopez-Puertas, M., B. Funke, S. Gil-Lopez, G. Mengistu Tsidu, H. Fischer, and **C.H. Jackman**, 2005: HNO_3, N_2O_5, and $ClONO_2$ enhancements after the October–November 2003 solar proton events, *J. Geophys. Res*., **110** (A09S44), doi:10.1029/2005JA011051.

***Loughman, R.P., D.E. Flittner**, B.M. Herman, **P.K. Bhartia, E. Hilsenrath** and **R.D. McPeters**, 2005: Description and sensitivity analysis of a limb scattering ozone retrieval algorithm, *J. Geophys. Res*., **110**, doi:10.1029/2004JD005429.

Mayr, H.G., and **J.G. Mengel**, 2005: Interannual variations of the diurnal tide in the mesosphere generated by the quasi-biennial oscillation, *J. Geophys. Res*., **110,** 10.1029/2004JD005055.

Mayr, H.G., **J.G. Mengel**, E.R. Talaat, H.S. Porter, and K.L. Chan, 2005: Mesospheric non-migrating tides generated with planetary wave: I Characteristics, *J. Atmos. Solar-Terr. Phys*., **67**, 1187.

Mayr, H.G., **J.G. Mengel**, E.R. Talaat, H.S. Porter, and K.L. Chan, 2005: Mesospheric non-migrating tides generated with planetary wave: II Influence of gravity waves, *J. Atmos. Solar-Terr. Phys*., **67**, 1287.

Mayr, H.G., **J.G. Mengel**, C.L. Wolff, 2005: Wave-driven equatorial annual oscillation induced and modulated by the solar cycle, *Geophys. Res. Lett*., **32** (L20811), doi:10.1029/2005GL023090.

Meloni, D., A. di Sarra, **J.R. Herman**, F. Monteleone, and S. Piacentino, 2005: Comparison of ground-based and TOMS erythemal UV doses at the island of Lampedusa in the period 1998–2003: the role of tropospheric aerosols, *J. Geophys. Res.,* **110** (D01202), doi:10.1029/2004JD005283, 2005.

Melott, A.L., B.C. Thomas, D.P. Hogan, L.M. Ejzak, and **C.H. Jackman**, 2005: Climatic and biogeochemical effects of a galactic gamma-ray burst, *Geophys. Res. Lett.,* **32** (L14808), doi:10.1029/2005GL023073.

Morris, G.A., M.R. Schoeberl**, B. Bojkov, L.R. Lait**, and M. Rex, 2005: A review of the Match technique as applied to SOLVE/THESEO and AASE-2/EASOE, *Atmos. Chem. Phys*. **5**, 2571–2592.

Patra, P.K., S.K. Behera, **J.R. Herman**, S. Maksyutov, H. Akimoto, and T. Yamagata, 2005: The Indian summer monsoon rainfall: interplay of coupled dynamics, radiation and cloud microphysics, *Atmos. Chem. Phys. Discuss.*, **5**, 2879–2895.

Rosenfield, J.E., and M.R. Schoeberl, 2005: Recovery of the tropical lower stratospheric ozone layer, *Geophy.s Res. Lett.***, 21,** doi:10.1029/2005GL023626.

***Rosenfield, J.E., S.M. Frith**, and **R.S. Stolarski**, 2005: Version 8 SBUV ozone profile trends compared with trends from a zonally averaged model, *J. Geophys. Res.,* **110**, doi:10.1029/2004JD005466.

Rohen, G., C. von Savigny, M. Sinnhuber, E.J. Llewellyn, J.W. Kaiser, **C.H. Jackman**, M.-B. Kallenrode, J. Schroter, K.-U. Eichmann, H. Bovensmann, and J.P. Burrows, 2005: Ozone depletion during the solar proton events of October/November 2003 as seen by SCIAMACHY, *J. Geophys. Res.,* **110** (A09S39), doi:10.1029/2004JA010984.

Semeniuk, K., J.C. McConnell, and **C.H. Jackman**, 2005: Simulation of the October–November 2003 solar proton event in the CMAM GCM comparison with observations, *Geophys. Res. Lett.,* **32** (L15S02), doi:10.1029/2005GL022392.

Stevens, M.H., C.R. Englert, **M.T. DeLand**, and M. Hervig, 2005: The polar mesospheric cloud mass in the Arctic summer, *J. Geophys. Res.,* **110** (A02306), doi:10.1029/2004JA010566.

Stevens, M.H., R.R. Meier, X. Chu, **M.T. DeLand**, and J.M.C. Plane, 2005: Antarctic mesospheric clouds formed from space shuttle exhaust, *Geophys. Res. Lett.,* **32** (L13810), doi:10.1029/2005GL023054.

Textor, C., M. Schulz, S. Guibert, S. Kinne, Y. Balkanski, S. Bauer, T. Berntsen, T. Berglen, O. Boucher, **M. Chin**, F. Dentener, **T. Diehl**, R. Easter, H. Feichter, D. Fillmore, S. Ghan, **P. Ginoux**, S. Gong, A. Grini, J. Hendricks, L. Horowitz, P. Huang, I. Isaksen, T/ Iversen, S. Kloster, D. Koch, A. Kirkevåg, J.E. Kristjansson, M. Krol, A. Lauer, J.F. Lamarque, X. Liu, V. Montanaro, G. Myhre, J. Penner, G. Pitari, S. Reddy, O. Seland, P. Stier, T. Takemura, T. and X. Tie, 2005: Analysis and quantification of the diversities of aerosol life cycles within AeroCom, *Atmos. Chem. Phys. Discuss*., **5**, 8331–8420.

Thomas, B.C., **C.H. Jackman**, A.L. Melott, C.M. Laird, **R.S. Stolarski**, N. Gehrels, J.K. Cannizzo, and D.P. Hogan, 2005: Terrestrial Ozone Depletion due to a Milky Way Gamma-Ray Burst, *Astrophys. J.*, **622**, L153–L156.

*Torres, O., P. K. Bhartia, A. Syniuk, E. Welton, and B. Holben, 2005: Total Ozone Mapping Spectrometer measurements of aerosol absorption from space: Comparison to SAFARI 2000 ground-based observations, *J. Geophys. Res.,* 110, D10S18, doi:10.1029/2004JD004611.

Vasilkov, A.P., **J.R. Herman**, **Z. Ahmad**, M. Kahru, and G. Mitchell, 2005: Assessment of the ultraviolet radiation field in ocean waters from space-based measurements and full radiative transfer calculations, *Appl. Optics*, **44**(14), 2863–2869.

Vautard, R., B. Bessagnet, **M. Chin**, and L. Menut, 2005: On the contribution of natural Aeolian sources to particulate matter concentrations in Europe: Testing hypothesis with a modeling approach, *Atmos. Envi.,* **39**, 3291–3303.

Viereck, R.A., L.E. Floyd, P.C. Crane, T.N. Woods, B.G. Knapp, G. Rottman, M. Weber, L.C. Puga, and **M.T. DeLand**, 2005: A composite Mg II index spanning from 1978 to 2003, *Space Weather,* **3** (S10005), doi:10.1029/2004SW 000084.

***Wenig, M**., B. Jähne, and U. Platt, 2005: Operator representation as a new differential optical absorption spectroscopy formalism, *Appl. Optics*, **44**(16), 3246–3253.